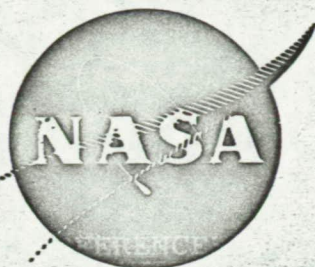


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Quiet Clean Short-Haul Experimental Engine (QCSEE)

Over-The-Wing (OTW) Propulsion System Test Report

Volume I - Summary Report

by

Advanced Engineering and Technology Programs Department

GENERAL ELECTRIC COMPANY

January 1978

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16. Abstract The Quiet, Clean, Short-Haul, Experimental Engine (QCSEE) Program includes the design and testing of high-bypass, geared-turbofan engines, with nacelles, forming the propulsion systems for short-haul, passenger aircraft. These systems contain the technology required for externally blown-flap-type aircraft for introduction into passenger service in the 1980's. This report covers sea-level, static, ground testing of the Over-the-Wing (OTW) engine and boilerplate nacelle components. The report consists of four volumes and two appendices as follows: <table border="0" style="width: 100%;"> <tr> <td style="width: 30%;">Volume I</td> <td>Summary Report NASA CR-135323</td> <td rowspan="6" style="vertical-align: middle; font-size: 3em;">}</td> <td rowspan="6" style="vertical-align: middle;">For Government Use Only</td> </tr> <tr> <td>Volume II</td> <td>Aerodynamics and Performance NASA CR-135324</td> </tr> <tr> <td>Volume III</td> <td>Mechanical Performance NASA CR-135325</td> </tr> <tr> <td>Volume IV</td> <td>Acoustic Performance NASA CR-135326</td> </tr> <tr> <td>Volume A</td> <td>Detailed Engine Performance</td> </tr> <tr> <td>Volume B</td> <td>Acoustic Data</td> </tr> </table>						Volume I	Summary Report NASA CR-135323	}	For Government Use Only	Volume II	Aerodynamics and Performance NASA CR-135324	Volume III	Mechanical Performance NASA CR-135325	Volume IV	Acoustic Performance NASA CR-135326	Volume A	Detailed Engine Performance	Volume B	Acoustic Data
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1.0 SUMMARY

The QCSEE OTW Propulsion System was tested at General Electric's Peebles, Ohio Outdoor Test Site 4D during the second quarter of 1977. Approximately 56 hours of engine operation were completed, including mechanical and controls checkout, aeroperformance mapping with a bellmouth inlet and hard-wall boilerplate nacelle, performance rating checks with a high Mach number inlet, reverse-thrust performance testing, acoustic baseline and fully suppressed forward- and reverse-thrust acoustic tests, and transient throttle-response demonstrations.

Engine performance in the forward mode met objective thrust and sfc goals, although at a somewhat higher turbine inlet temperature than predicted. These goals reflected the axial thrust component of an equivalent conical exhaust nozzle. The actual "D" shaped OTW exhaust nozzle provided somewhat greater flow-turning (kickdown) and had a lower velocity coefficient than predicted from scale-model testing.

The reverse-thrust goal, 35% of maximum forward thrust, was met both at 105° and at 115° blocker angles at 81% fan speed. The 105° blocker angle was selected for acoustic testing to reduce fan back pressure and blade stress.

Fan performance was very satisfactory, exceeding the predicted airflow levels and hub pressure ratio and efficiency objectives.

Mechanical operation of the engine was very satisfactory, with no serious system criticals or other vibratory problems throughout the operating range. Some oil leakage occurred from the composite frame at the accessory gearbox mount seal. This was corrected on the test stand by the addition of Furane adhesive in the frame. No further evidence of oil leakage was observed, although some loss of oil continued during high speed running.

Acoustic data indicated sideline noise levels below the 95 EPNdB goal at approach and 1.5 dB above the goal at takeoff. At maximum reverse thrust, the 100 PNdB goal was exceeded by 6.5 dB, as predicted. Because of using a common fan discharge duct with the UTW engine, the velocity entering the thrust reverser was higher than desired (resulting in a higher pressure loss in the turn). This necessitated a higher throttle setting to achieve the required reverse thrust, and the resulting noise level was higher than it would be in a more optimum design.

Throttle response using core stator reset met the objective of one second from 62% to 95% thrust. All operation using the full authority digital control was stable and trouble free.

In summary, engine performance and mechanical operation were very satisfactory, and the overall noise level was considered to be very good in view of the difficult objectives.

2.0 INTRODUCTION

The General Electric Company is currently engaged in the Quiet, Clean, Short-haul, Experimental Engine (QCSEE) Program under Contract NAS3-18021 to the NASA Lewis Research Center. The Over-the-Wing (OTW) experimental engine was designed and built under the program to develop and demonstrate technology applicable to engines for future commercial, short-haul, turbofan aircraft. The initial buildup of the OTW engine and boilerplate nacelle was tested at General Electric's Peebles, Ohio Outdoor Test Site 4D during the period from March 31, 1977 through June 9, 1977.

The "D" shaped OTW exhaust nozzle contained a moveable roof that could be positioned to form a thrust-reverser blocker. The exhaust nozzle was run in the inverted position so that, during reverse-thrust testing, the exhaust gases would be directed downward rather than into the test facility and instrumentation lines.

Initial testing included a mechanical and systems checkout with hard-wall acoustic panels and a bellmouth inlet. Performance data were taken over a range of fan speeds and at three exhaust nozzle areas (side door angles). This phase of testing provided data in the range of takeoff and approach operating conditions to explore "uninstalled" performance with minimum loss of ram recovery. Fan performance characteristics were mapped over a range of fan speeds and operating lines. An acoustic baseline was also run in the unsuppressed, forward-thrust configuration.

The inlet was then changed to the boilerplate high Mach number design to investigate installed performance with real ram-recovery losses. Points were repeated at takeoff and approach operating conditions. Reverse-thrust testing included 105° and 115° blocker angles with a 0.6 lip-length ratio. A reingestion shield, 3.66 m (12 ft) in diameter and 9.14 m (30 ft) long was used to reduce reingestion of hot exhaust gases during reverse-thrust testing, and the effect of this shield on thrust measurements was calibrated in the forward-thrust mode.

Following reverse-thrust performance testing, all hard-wall panels were changed to acoustically treated panels, and an acoustic splitter was added in the fan duct. Fully suppressed acoustic data were taken in the reverse and forward-thrust modes. Additional acoustic tests were then conducted to evaluate the contribution of inlet treatment and the combined effect of the splitter and core exhaust nozzle treatment.

Following the completion of acoustic testing, additional tests were conducted to evaluate control characteristics and engine throttle response in the forward-thrust mode.

The engine was inspected, refurbished, and delivered to NASA Lewis Research Laboratory on June 30, 1977 for further planned testing adjacent to a wing section.

This volume of the propulsion system test report includes a description of the equipment tested and the test facility, a summary of the instrumentation, a chronological history of the test, and a summary of the results.

3.0 DESCRIPTION OF EQUIPMENT TESTED

The Over-The-Wing propulsion system* (see Figure 1) included a high bypass-ratio, gear-driven fan and a YF101 core engine and low pressure turbine. The fan frame was an all-composite structure forming a section of the nacelle wall. The aft fan duct and core cowl were boilerplate components having interchangeable hard-wall and acoustic-suppression panels. The exhaust nozzle was a "D" shaped, mixed-flow design, providing area variation by hinged side doors and providing a target-type thrust reverser by rotating a section of the nozzle roof. The core exhaust nozzle consisted of a shroud and plug with both hard-wall and acoustically treated metal parts available. The engine was tested with two inlets: a bellmouth design for performance calibration and an accelerating inlet designed to produce 0.79 throat Mach number to suppress forward-radiated, fan noise. A more detailed description of these components follows. A cross-section drawing of the propulsion system is provided in Figure 2.

3.1 FAN ROTOR ASSEMBLY

The 28-bladed OTW fan was made of titanium for economic reasons, but the configuration is based on a flight design that would be fabricated from composite material. The blades are attached to the titanium disk by a single-tooth dovetail. A major design feature is the high hub pressure ratio used to supercharge the core engine.

3.2 MAIN REDUCTION GEAR

The main reduction gearset for the OTW engine is an epicyclic star configuration developed by Curtiss-Wright Corporation. The low pressure turbine rotor is splined to a sun gear which drives a ring gear through a set of eight star gears. The star gears are mounted on tandem, spherical, roller bearings which are mounted on a fixed carrier. Lubrication requirements for the reduction gear vary between approximately 1011 cm³/sec (16 gpm) at idle to approximately 1847 cm³/sec (29 gpm) at takeoff. The gear ratio is 2.062, and both the input and output are flexibly mounted to prevent engine deflections from influencing the gear operation.

3.3 FAN FRAME

The fan frame is an all-composite, static structure formed from the integration of several separate structures. The outer casing of the frame combines the function of the nacelle with the frame outer shell. This casing provides part of the external nacelle surface as well as the internal fan flow path. Fan blade tip treatment is provided by a grooved structure

*NASA CR-134848 - "Over-the-Wing (OTW) Final Design Report."

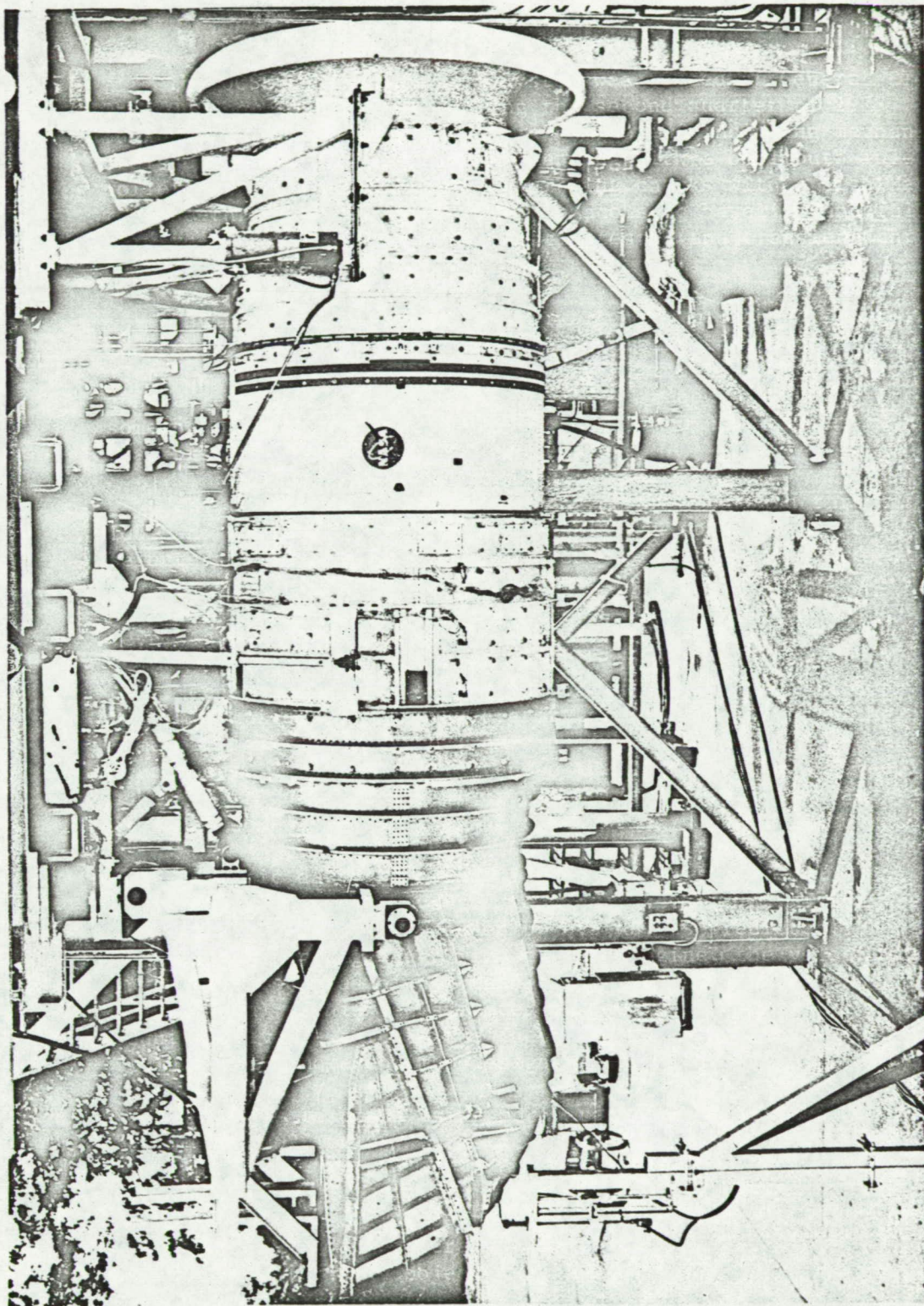


Figure 1. QCSEE OTW Experimental Propulsion System Installation.

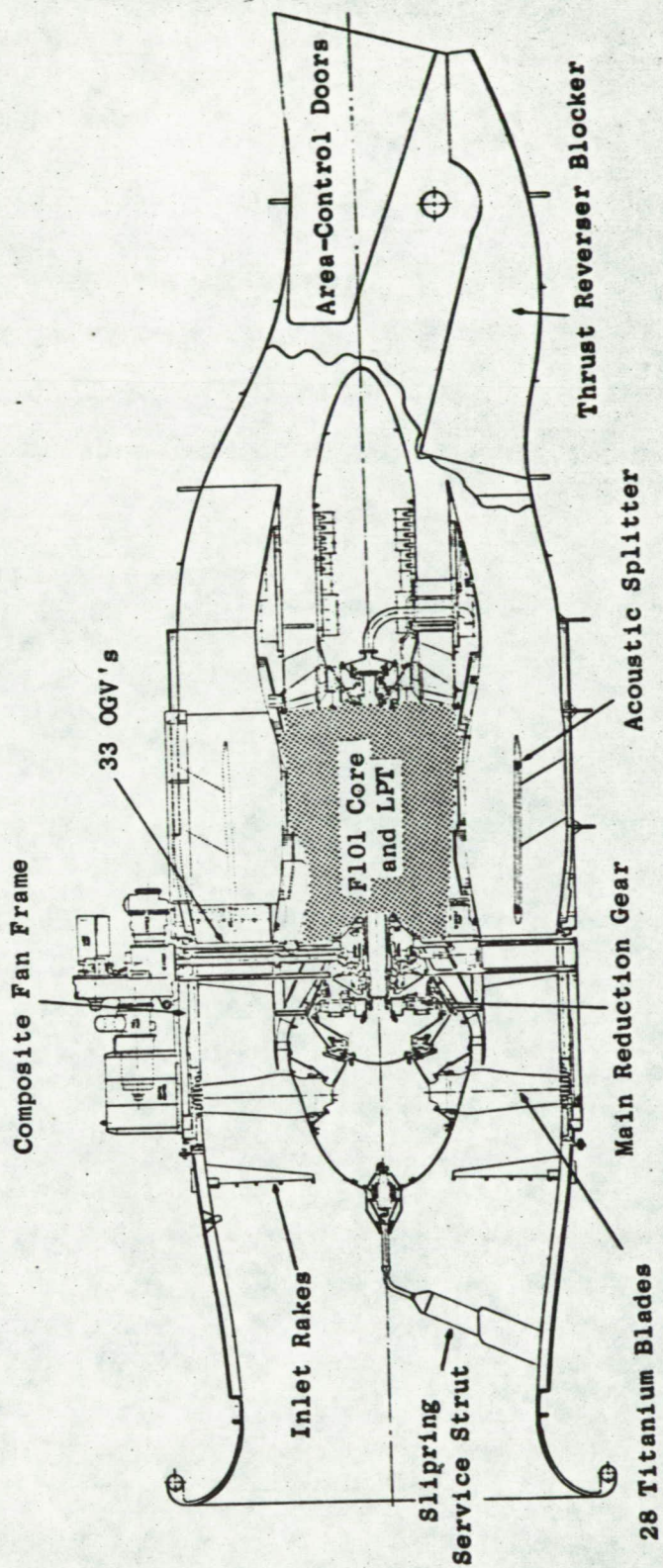


Figure 2. OTW Propulsion System Cross Section.

integrated into the forward portion of the outer casing. Containment of failed composite airfoils is provided by a felted Kevlar band in the outer casing. Positioning of the fan and core engine relative to the outer casing is provided by 33 vanes which also serve as the fan-bypass stator vanes. The hub of the frame is connected to the frame splitter through six equally spaced struts. The inner shell of the outer casing, the bypass duct and core duct surfaces of the frame splitter, and the pressure faces of the bypass vanes are perforated to provide acoustic suppression within the frame structure. The forward end of the compressor attaches to the rear of the frame at the exit of the frame inner airflow path. The outer cowl doors attach by a tongue-and-groove arrangement to the outer casing at the rear of the frame. The core cowl doors attach in a similar manner to an extension bolted to the back of the frame. The inlet is attached to an adapter which is attached to the forward end of the casing by 16 rotary latches. The frame also provides the major support point for the engine through a uniball and two thrust mounts located at the top of the core cowl.

Flow turning of the fan flow into the core is provided by an independent set of metallic outlet guide vanes attached to the forward flange of the frame hub. The splitter is formed from sheet metal with the stator vanes penetrating and brazed to the skins.

3.4 CORE ENGINE

The QCSEE OTW engine utilized the YF101 core with modifications described as follows.

The nine-stage, highly loaded compressor is designed for 12.5 pressure ratio at 27.2 kg/sec (60 lb/sec) corrected flow. The IGV and stage 1-3 vanes are variable to control stall margin and performance at part-speed conditions. The stator schedule was modified to high-flow the compressor above 83% corrected speed and to provide additional stall margin in the starting range. The schedule change necessitated minor modifications to the actuation linkage, and an electric feedback was used in place of the F101 splined-shaft system.

The YF101 first-stage compressor blades have leading and trailing edges "cropped" at the tip. The QCSEE engines utilized the full-span PV airfoil mounted on the PFRT dovetail. The mechanical rotor speed limit was set at 14,050 rpm to ensure adequate vibratory margin.

The OTW engine used the PFRT scroll dome combustor. A single, manually operated ignitor was used in place of the F101 dual, automatic system.

The YF101 high pressure turbine used in the QCSEE engine is a single-stage design utilizing very high tip speed to achieve the required level of energy extraction in a single stage. Cooling air is introduced into the rotor through an inducer located inboard of the nozzle vanes. The vanes are film/impingement cooled by CDP air. The OTW engine used F101 "warm bridge"

blades having demonstrated high temperature and cyclic life advantages over the PFRT design. The blades were frequency screened to ensure that the two-stripe vibratory mode is resonant with vane passage frequency well above the operating range. HPT shrouds were of the improved PV design.

The low pressure turbine of the OTW engine was identical to the YF101 two-stage, tip-shrouded design except that the PV second-stage blade was used. This blade is slightly decambered to reduce the exit swirl resulting from increased energy extraction. The turbine frame vane/struts were extended 2.54 cm (1 in.) forward to accept the greater turbine exit swirl. The frame was also modified to provide engine mounts not required in the long-duct F101.

The HPT diaphragm area was increased to provide 5% larger flow function, and the LPT area was reduced to provide 5% smaller flow function than in the F101. These changes, required for cycle matching, were accomplished by rotating the vanes slightly in the bands before brazing.

In order to locate the ignitor plug in the pylon region and eliminate a space problem under the core cowl, the aft end of the engine was rotated 120° clockwise with respect to the compressor. The F101 infrared pyrometer was eliminated because the digital control provided the capability to instantaneously calculate T_{41} based on measured P_{S3} , T_{T3} , and W_f .

Because of the reduction gear system in the LP power train, the fan rotor thrust could not be balanced against the LPT rotor thrust. A balance piston was therefore added to the rear of the LPT rotor. CDP air was used to balance the turbine rotor thrust. Fan rotor thrust was carried by a high-capacity ball bearing in the fan frame.

3.5 DIGITAL CONTROL

The full authority digital electronic control manipulates variables in response to commands representing those which would be received from an aircraft propulsion system. The system utilizes an F101 hydromechanical control to provide a fuel stopcock and core-overspeed limiter. All fuel scheduling and core stator control are accomplished by the digital control.

The commands to the digital control are introduced through the control room elements consisting of an interconnect unit, operator panel, and engineering panel. They provide means for the engine operator to introduce commands, to switch between available operating modes, to adjust various control constants, and to monitor control and engine data. In addition to these digital commands from the control room, the system also receives a mechanical input in the form of a power lever angle (PLA) transmitted to the hydromechanical control. This serves as an input to the backup governor and operates a positive fuel-shutoff valve in the control.

The following control and engine variables are sensed by the control system:

- Core speed
- Low pressure turbine speed
- Core stator position
- Compressor discharge temperature
- Metering valve position
- Engine inlet static pressure
- Fan inlet temperature
- Free-stream total pressure
- Compressor discharge pressure
- Power lever angle
- Power demand

The digital control regulates fuel flow to meet accel/decel requirements to observe speed and T41 limits and to respond to power demand.

3.6 EXHAUST NOZZLE

The "D" shaped, mixed-flow exhaust nozzle is a boilerplate representation of a flight configuration designed to spread and turn the exhaust flow over the wing and flap. Exhaust area (A8) can be varied by changing the position of the side doors as shown in Figure 3. A portion of the nozzle roof rotates to form a thrust-reverser blocker door. The blocker-door reference angle can be set with respect to horizontal where 105° blocker angle corresponds to 70° of blocker rotation. The lip angle was designed to be 25° from horizontal with the blocker at 105°. The entire nozzle assembly was run in the inverted position to avoid impingement of the exhaust gases on the overhead facility and instrumentation lines when operating in the reverse mode.

3.7 CORE EXHAUST

The core exhaust has a fixed discharge area with a separate but interchangeable outer cowl that is bolted to the aft cone and can be trimmed for area adjustment. A radial service strut is located at the bottom centerline of the core exhaust to provide aerodynamic fairing over the oil inlet, oil drain, seal drain, and balance piston air lines through the core nozzle to the sump. The strut is designed so that the strut and service lines need not be disassembled to remove the centerbody or outer duct. Both the outer

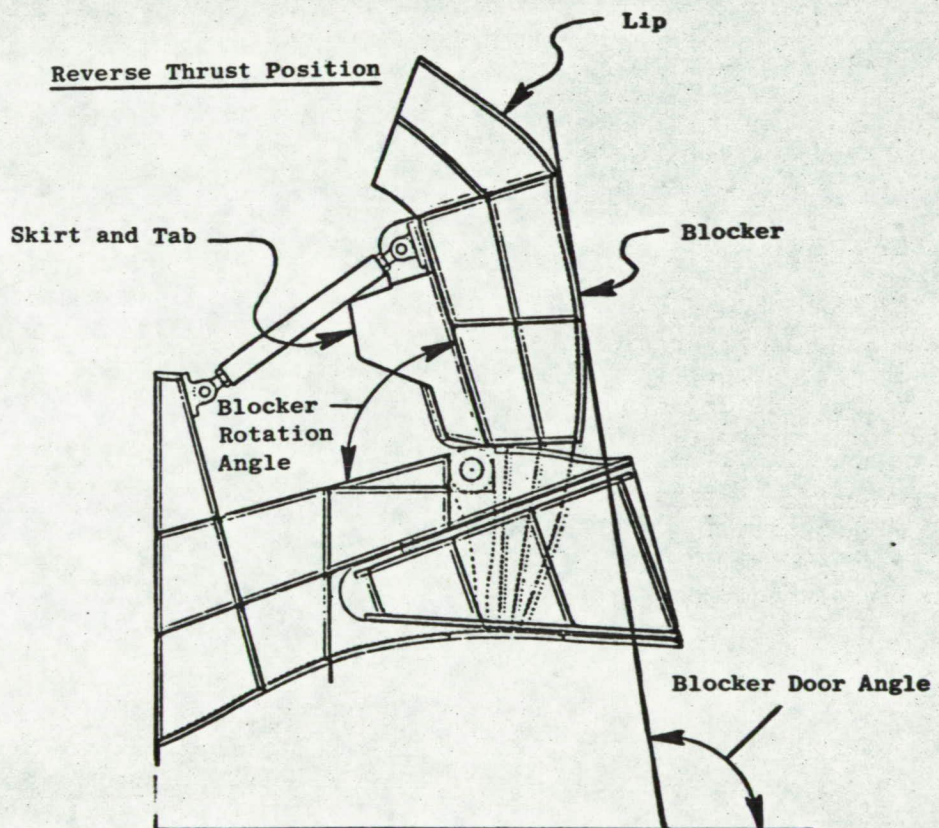
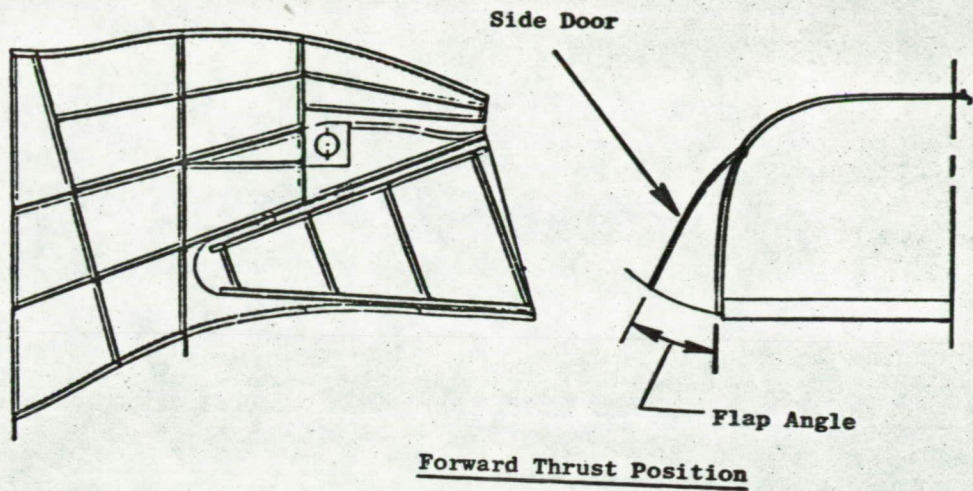


Figure 3. "D" Nozzle Geometry.

shroud and the centerbody have been fabricated both in hard-wall and in acoustically treated configurations.

3.8 ACCESSORY DRIVE SYSTEM

Engine accessory power is extracted from the core engine shaft through right-angle bevel gearing (two F101 inlet gearboxes). The power is transmitted through radial drive shafting to a top-mounted accessory gearbox and to a scavenge pump mounted in the core cavity area on the bottom vertical centerline. Mounted on, and driven by, the accessory gearbox are the fuel pump and control, lubrication supply pump, control alternator, and starter drive pad. The radial drive shaft between the internal bevel gear and the accessory gearbox has a central support bearing to eliminate shaft critical speed problems. The shaft between the internal bevel gear and the bottom-mounted scavenge pump does not require a central support bearing because of the short overall length.

3.9 INLET

Testing of the OTW engine required two boilerplate inlet configurations. The NASA Quiet Engine "C" bellmouth inlet was utilized for aerodynamic engine mapping. A hybrid configuration featuring elevated throat Mach number and multiple acoustic-suppression-design capability was employed for the aeromechanical evaluations. Both inlets were mechanically decoupled from the engine to prevent overload of the composite fan frame flange due to excessive motion/vibration. An air seal is provided by a bulb seal bolted to the inlet flange and pressed against the other. An acoustic seal is provided by lead foil in a vinyl cover. The two seals aerodynamically and acoustically simulate the hard-joint condition of a composite propulsion system assembly.

3.10 FAN COWLING

The OTW fan bypass duct is a fabricated aluminum sheet and stringer assembly consisting of two semicircular door structures that provide the attachment capability for an interchangeable set of acoustic-treatment panels and a matched set of hard-wall panels. Core cowl access is accommodated by the hinged door construction of the outer ducting. The outer fan doors are decoupled from the fan frame (to prevent the transmission of excessive nacelle weight to the fan frame), and the primary structural attachment to the pylon is made through two heavy-duty, piano-type hinges located at the top edge of the door assemblies. All forward and aft fan cowl loads are transmitted through the hinge to the facility structure. An extension is attached to the rear of the cowl doors to adapt the same doors used on the OTW engine to the OTW exhaust nozzle.

3.11 ACOUSTIC SPLITTER

The aft duct acoustic splitter assembly is a fabricated component of aluminum sheet metal skins, machined rings, and honeycomb core resulting in a double-sandwich construction. The leading and trailing edge close-outs are machined aluminum rings. The assembly consists of two semicircular structures supported from the fan duct doors by six stainless steel, airfoil-shaped struts. Silicon seals have been applied to the ends of the splitter halves to dampen potential vibratory movement during engine testing. The splitter is designed to be removable. Separate filler pieces which duplicate the strut feet can be inserted in the fan doors during engine operation without the splitter.

3.12 CORE COWL

The core cowl embodies the same design approach used for the fan duct. It is a stainless steel fabricated structure supporting interchangeable acoustic or hard-wall panels. It has a forward interface (Marman-type joint) with the fan frame and a rear interfacing slip joint with the core exhaust. Access to the compressor and turbine is provided by hinged-door construction. The core doors and skirt system are temporarily supported by the pylon through a set of pins when opened. The core cowl employs shop air for cooling. This air is ducted around the engine and released inside the core cowl; it exhausts upward through the pylon.

3.13 ENGINE MOUNTS

All boilerplate nacelle hardware is supported from the test stand. Normal engine thrust and other operating loads are carried through the main engine mounts to the test stand. Thrust, vertical, and side loads are reacted at the front mount; vertical, side, and torque loads are taken by a three-link arrangement at the rear mount plane on the outer shell of the turbine frame.

3.14 FUEL SYSTEM

The fuel-delivery system is composed of F101 engine main fuel system components. The system includes the hydromechanical control, main fuel pump, and fuel filter.

3.15 IGNITION SYSTEM

The ignition system consists of an ignition exciter box, ignition lead, and spark ignitor located in the pylon. These components are of CFM56 design. The system will permit continuous sparking with a stored exciter energy of 14.5 to 16.0 joules for a delivered nominal spark energy of two joules at a nominal rate of two sparks/second. The ignition system is powered by a

facility supply which provides 115 volt - 400 Hz power through permanent facility wiring to the engine-mounted ignition box. A momentary contact pushbutton on the Engine Control Module (ECM) is used to turn on the ignition system. The pushbutton legend, labeled "ON," is illuminated while the pushbutton is held in the depressed position and goes off when the push button is released.

3.16 STARTING SYSTEM

An air turbine starter and control valve are mounted on the accessory gearbox. The facility system provides a regulated flow of filtered air to the engine starter for engine motoring operations. Controls are located on the ECM in the control room. The system has been designed to deliver up to 2.26 kg/sec (5 lb/sec) of shop air at 414 kN/m^2 (60 psig).

In the normal mode of operation, the air-start system can be operated only when the engine speed is below the minimum engagement speed set on the starter-protection module and when the main facility fuel valve is open. An emergency mode of operation bypasses the engine-speed and fuel-valve interlocks and permits the cell operator to motor the engine in any emergency, such as to blow out an internal fire or to motor the engine after a flameout until it has cooled sufficiently for a safe shutdown.

3.17 SLIPRING

A 100-point, no-leak, minislipring was used to transmit blade and ring-gear strain signals. Leadout and cooling form lines were routed through a slipring service strut mounted in the inlet. The strut also acts as an antirotational device for the slipring.

3.18 SLAVE LUBRICATION PACKAGE

The QCSEE slave lube system (Figure 4) is an off-engine-mounted package that conditions and stores the Royal 899 lube oil. Flexible hoses are used to connect the package to the engine components. All fluid connections to the package are located on a common bulkhead on the base of the package. Electrical connections for oil level and cooling-water-flow measurements are made directly to connectors on the measuring devices. A leak-tight, drip pan with a drain connection is provided in the base of the package. The package has been designed to receive and condition up to $9450 \text{ cm}^3/\text{sec}$ (150 gpm) of aerated, scavenge-return oil at temperatures up to 450 K (350° F). The oil cooling system rated capacity is 422,000 J/sec (24,000 Btu/min) using $9450 \text{ cm}^3/\text{sec}$ (150 gpm) of water.

Principal components of the QCSEE slave lube package are the main oil tank, scavenge oil filter, water oil heat exchangers, water filters, water flowmeter, and water-flow-control valve.

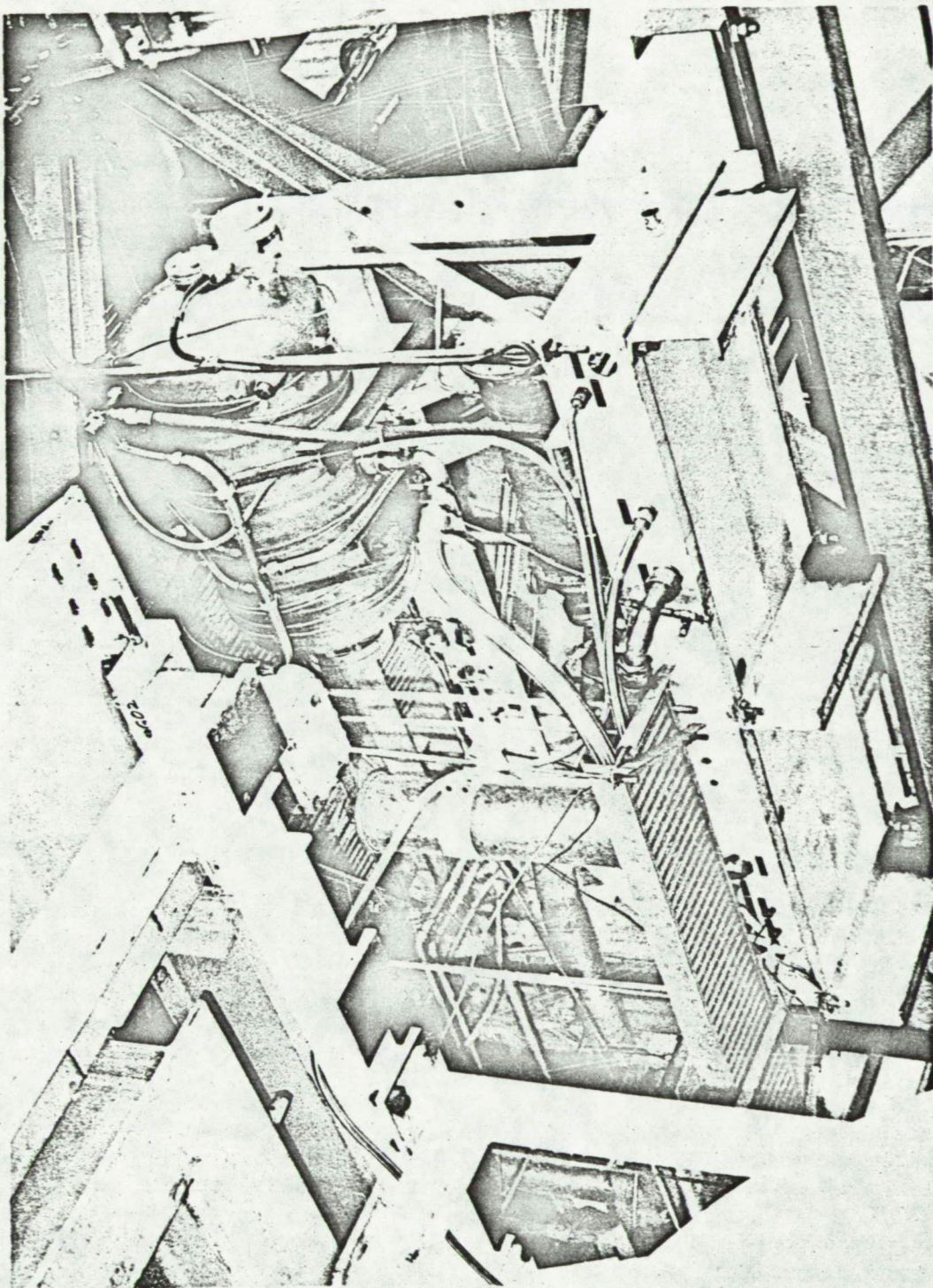


Figure 4. Slave Lube Package.

Hot, aerated, scavenge-return oil is pumped to the package by the engine-mounted scavenge pump. The scavenge oil first flows through the scavenge oil filter where particles, 10 microns and larger, are filtered out of the oil. If the retention capacity of the filter element is exceeded, a bypass valve opens at $345 \text{ kN/m}^2 \pm 35 \text{ kN/m}^2$ (50 psid \pm 5 psi) to maintain lube flow. Before the bypass condition is reached, however, a "Lube Scavenge Hi ΔP " warning is given to the test operator.

Bypass indication is also provided on the filter. At $276 \pm 35 \text{ kN/m}^2$ (40 psid \pm 5 psi), a red button "pops up" and becomes visible in the sight-glass atop the filter, thus, providing visual indication at the slave lube package that the filter is about to bypass or is bypassing (depending on the actual pressure drop across the filter). The red button will remain in the "up" position until the sight-glass is removed and the button is manually depressed. Pressure taps are provided upstream and downstream of the scavenge oil filter to monitor the pressure drop across the filter.

The hot, aerated, filtered oil then passes through the water/oil heat exchangers where it is cooled to 345 K (160° F) by controlling the water flow through the heat exchangers.

From the heat exchanger, oil is routed to the scavenge return port on the main oil tank. On entering the main oil tank, the oil is deaerated by flowing through the vortex generator located in the tank inlet. The cooled, filtered, deaerated oil drains into the tank where it mixes with the oil reserve in the tank. Clean, cooled, deaerated, lube oil is drawn through a discharge line from the tank as required to supply oil to the engine-mounted lube pump.

4.0 DESCRIPTION OF TEST FACILITY

The QCSEE OTW engine was tested at General Electric's Peebles, Ohio remote test site (see Figure 5). Engine installation was Site 4, Pad D, aeroacoustic test facility. This test facility is located 80 miles due east of the General Electric, Evendale, Ohio Plant and is readily accessible by road or air.

The facility provided for fuel, cooling water, facility and instrument air, fire protection, and thrust measurement systems. An "off engine" lube system was designed and constructed for the QCSEE Program and installed on the test stand (reference Figure 4).

Fuel is stored at a remote fuel farm (see Figure 6) and is pumped through underground lines to the test pad where it passes through a 10-micron filter before going to the engine. During engine test, the fuel stopcock is operated from the facility control room. JP-5 fuel was used on the QCSEE OTW engine test.

Water for cooling is pumped from a reservoir located on the test facility grounds. The water is filtered prior to entering the test pad manifold. Cooling water was used in the "off engine" lube system heat exchanger and was remotely controlled from the Pad D control console. Water flow was measured by use of a turbine flowmeter and was displayed and recorded during engine test. Adjustments to the water flow were required during engine test to maintain a constant oil temperature in the lube system supply. Water flow was varied between 0 and 0.30 m³ (0 and 80 gal) per minute.

The facility air supply is a regulated and filtered system. Facility air was used for the air-start system and under-cowl cooling. Each of these systems was individually controlled and remotely operated from the control console during engine test. Instrument air is a dried-air system used on the electropneumatic-valve controllers, digital control, and slipping system.

The facility has both water-sprinkler and inert-gas, fire-protection systems. Sprinkler heads are located in the facility structure; the inert-gas system is connected for use through the engine air-cooling system. Both systems can be operated from the test pad or the control room. In addition to these systems, dry chemical fire extinguishers are located at the pad for use by Peebles test personnel (who have been instructed in their use).

Engine thrust was measured using a three-bridge, 266,000-N (60,000 lbf), load cell. The thrust system was calibrated for forward and reverse thrust before and after testing.

The "off engine" lubrication system provided the lube oil conditioning and oil storage facilities required for engine operation. Several modifications to the system were required to allow extended engine running. These

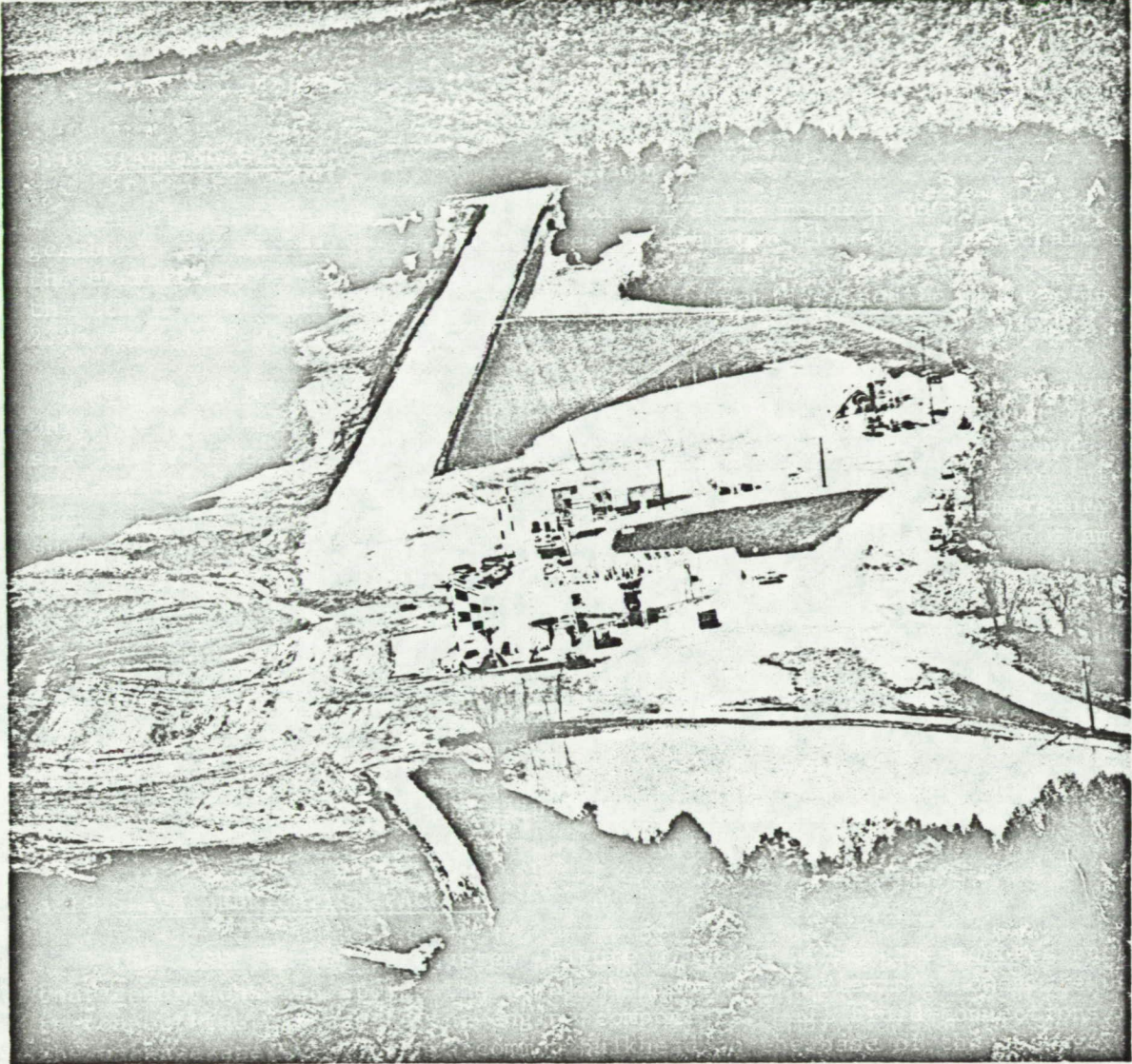


Figure 5. Peebles Ohio Test Site 4.

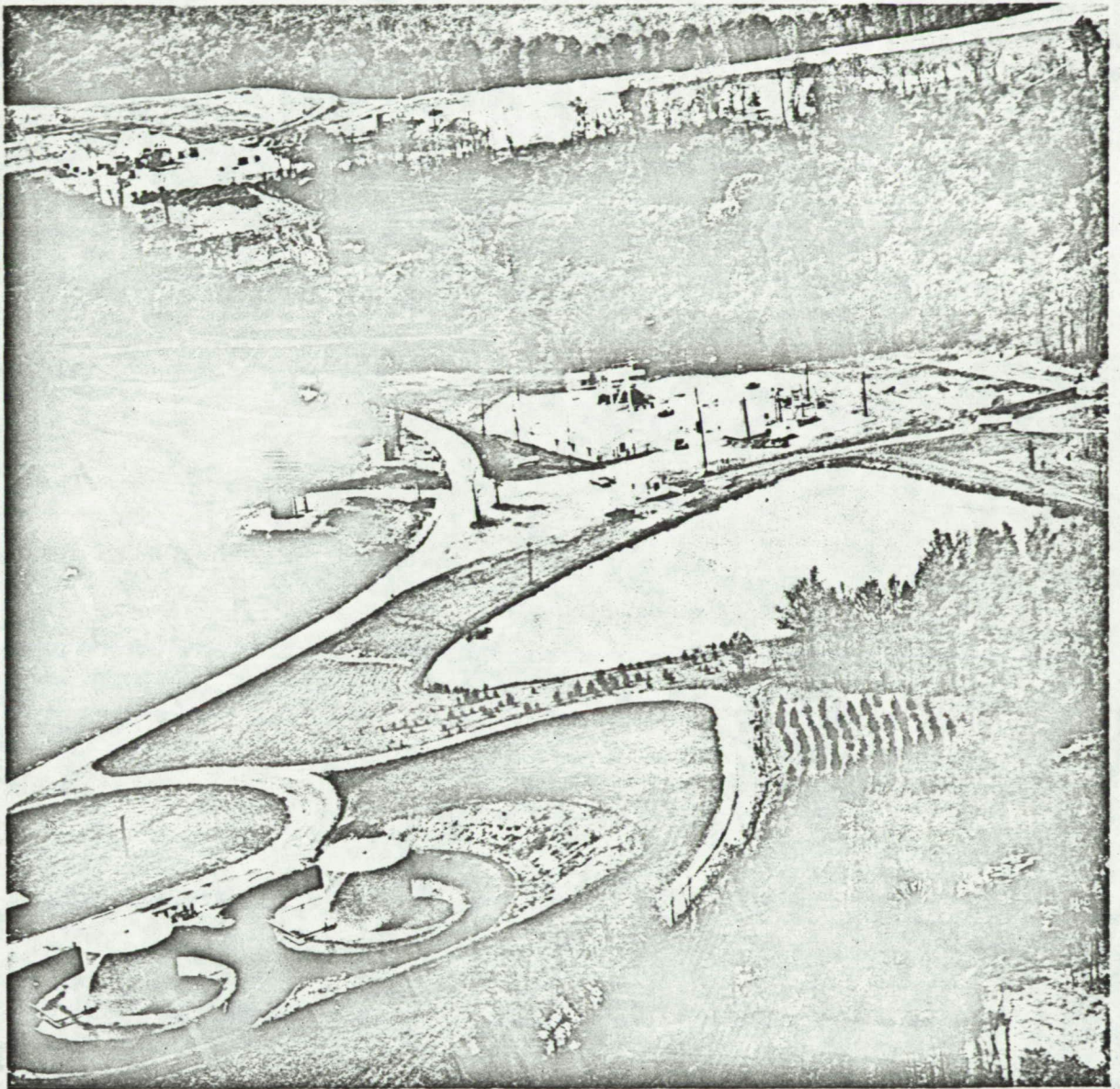


Figure 6. Peebles Ohio Fuel Farm.

modifications included increased lube tank capacity, addition of a second oil/water cooler, and a slave scavenge pump for the accessory gearbox. The lube system is defined on the following drawings:

Assembly	4013180-700
Schematic	4013180-853
Engine Connections	4013180-865
Lube Tank	4013187-581
Heat Exchanger Addition	4013187-639

With the modified, off-engine system the storage capacity was 0.166 m^3 (44 gal) with tank level readout set for between 0.083 and 0.166 m^3 (22 and 44 gal). The system was regulated to deliver up to $0.003 \text{ m}^3/\text{sec}$ (50 gpm) of cooled, filtered, deaerated oil to the engine lube pump at temperatures between 333 K (140° F) and 342 K (160° F). The slave scavenge pump for the accessory gearbox prevented the overtemperature problem by eliminating the flooding condition in the accessory gearbox encountered during initial UTW testing.

The test pad was equipped to handle the following instrumentation connections:

- 200 temperature sensors, including reference thermocouples
- 384 pressure sensors (air type), including eight vents
- 200 analog circuits (two wire-shielded pairs)
- 600 safety monitoring circuits to engine control console
- 6 traversing probe actuator circuits

Instrumentation was connected in accordance with the Test Request and Test Request Changes. Recording equipment was located at the test facility control room and also at Evendale's Instrumentation Data Center. Reference the Test Request for recorder and control room setup.

A minislipping system was used for connection of fan rotor and ring gear instrumentation. The slipping coolant console was located in the facility overhead and monitored in the control room during engine testing. Reference drawings 40130181-988 and 4013180-279 for this system.

The facility is equipped with far-field microphones and stands with further provisions for near-field microphones using portable stands.

5.0 TEST INSTRUMENTATION

Because of many new features incorporated in the initial testing of the OTW propulsion system, an abnormally large quantity of steady-state and transient instrumentation was employed. This instrumentation fell into the following general categories.

1. Operational Safety Instrumentation

This information was displayed on the control console and either logged manually for each steady-state data point, or recorded automatically by the Automatic Data Handling (ADH) System. Several types of control-console displays were employed including panel meters, digital indicators, warning lights, and two Metrascope units. This instrumentation is listed in Tables I through IV.

2. Dynamic Instrumentation

This information primarily included strain gages and accelerometers. Data were displayed on oscilloscopes and Schlumberger Analyzers and were continuously recorded on three magnetic tape recorders. This instrumentation is listed in Tables V, VI, and VII.

3. Transient and Control Parameters

These parameters were continuously recorded on four Sanborn recorders. The parameters are listed in Table VIII.

4. Digital Control Data

The digital control was designed to communicate to and from the control room via an interconnect unit and two control panels: an Operator's Panel on the control console and an Engineering Panel adjacent to the console.

The Operator's Panel, in addition to the power demand lever, incorporated digital displays of critical engine parameters as listed in Table IX.

The Engineering Panel contained control potentiometers for manual inputs to the digital control and a digital display to read out any of 48 parameters in binary code. These parameters were also printed out on paper tape on command during each data reading.

5. Performance Instrumentation

Internal engine pressures and temperatures from rakes, static taps, and probes were recorded automatically for each data point by the ADH System. These parameters are listed in Table X.

Table I. Safety Instrumentation.

Item Numbers	Description	Press.	Temp.	Strain Gage	Accel	Other
011001, 2	No. 3 Bearing Temp.		2			
011003, 4	Forward Sump Cavity	2				
011005	Aft No. 3 Bearing Support	1				
011006	HPT 1/Rev.					(1) a/Rev.
011901, 2	No. 3 Bearing Vib.				2	
031001	Radial Drive Shaft Bearing		1			
032901, 2	AGB Vib				2	
033001-033008	Reduction Gear Bearing		8			
033009	Reduction Gear Oil Supply	1				
033010, 11	Red. Gear Prox. Probe					(2) Prox. Probes
033901, 2	Reduction Gear Vib				2	
070001	VSV, Stator Pot					(1) VSV
070901, 2	Compressor Aft Flng. Vib				2	
124002, 3	Plane 3 Probes	1	1			
231901	Exh. Cone Vib				1	
323001, 2	Fuel Manifold Press.	2				
323003, 4	Fuel Temperature		2			
323005	Fuel Inlet Press.	1				
323006, 7	Fuel Flow					(2) Flowmeters
323008	Fuel Manifold Temp.		1			
402001, 2	Lube Pump Disch. Press.	2				
404001, 2	Lube Scav. Disch. Press.	2				
404003, 4	Lube Scav. Disch. Temp.		2			
404005	Lube Scav. Filter Delta Press.	1				
404008, 9	Lube Supply Temp.		2			
404010	HX Water Flow					(1) Flowmeter
404011, 12	HX Water Temp.		2			
404013	Oil Level					Oil Level Sensor
417001	Lube Supply Filter Delta Press.	1				
650901	Digital Control Vib.				1	
811001, 2	No. 1B Bearing Temp.		2			
811003, 4	Fan Rotor Cav. Press.	2				
811005	No. 1 Seal Air Press.	1				
811901, 2	No. 1 Bearing Support Vib				2	
812001, 2	No. 1 R Bearing Temp.		2			
813001, 2	No. 2 Bearing Temp.		2			
813901, 2	No. 2 Bearing Support Vib				2	
830901	Slipring Vib.				1	
835801-835812	Fan OCV Strain Gages			12		
840801-840811	Fan Frame Strain Gages			11		
840901, 2	Fan Frame Vib.				2	
845001-845008	Core Cowl Skin Temp.		8			
845013-845024	Under Cowl Cavity Temp.		12			
845901	Core Cowl Vib				1	
911001, 2	No. 5 Bearing Temp.		2			
911003	No. 5 Bearing Support Temp		1			
911004-911009	Aft Sump Cav.	4	2			
911010, 11	No. 6 Seal Air Cav. Temp.		2			
911012	No. 6 Seal Forward Cav. Temp		1			
911013	No. 6 Seal Fwd. Cav. Press	1				
911014	No. 6 Seal Support Temp.		1			
911015	No. 6 Seal Delta Press.	1				
911016, 17	Bal. Cav. Press	2				
911018, 19	Bal. Cav. Temp.		2			
911020-911025	Aft Sump Air Temp.		6			
911030, 31	Aft Sump Scav. Temp.		2			
911901, 2	No. 5 Bearing Support Vib				2	

Table II. Control Console.

The following parameters were continuously displayed in engineering units on the control console.

Item	Parameter	Full Data Point
402001	Lube Pump Discharge Pressure	Log-ADH
404001	Scavenge Pump Discharge Pressure	Log-ADH
011005	Cavity aft of No. 3 Bearing Pressure	Log
911016	Balance Cavity Pressure	Log
000009	Starter Air (Starts Only)	Log
033009	Reduction Gear Oil Supply Pressure	Log
811005	No. 1 Seal Air Supply Pressure	Log
323001	Fuel Manifold Pressure	Log
404014	Oil Tank Pressure	Log
323005	Fuel Pump Inlet Pressure	Log
000008	PS3C	Log
000007	False PS3C	Log
---	Slipring Pressurization	---
011003	Forward Sump Pressure	ADH
---	Instrument Air Pressure	---
911015	No. 6 Seal/Aft Sump ΔP	Log-ADH
417001	Lube Supply Filter ΔP	Log
404005	Lube Scavenge Filter ΔP	Log
830000	Fan Speed	Log-ADH
230044	T5 Panel Meter	Log
050000	Core Speed	Log-ADH
404013	Lube Level	Log
323006	Main Fuel Flow	Log-ADH-SNBRN
323007/404010	Verification Fuel Flow/Water Flow	Log-ADH-SNBRN/Log
230044	T5 Digital	Log
000006	Throttle Position	Log
070001, 2	VSV Position	Log-ADH
000001	Thrust	Log-ADH

Table III. Control Console Panel Vibration Display.

Vibration Metroscope (20 Channel)

Fan-and LPT Tracking Filters
(12 Indications of Vibration)

	<u>Item</u>	<u>Full Data Point</u>
Fan Frame Horizontal	840902	Log 2
Fan Frame Vertical	840901	Log 2
No. 1 Bearing Support Vertical	811901	Log 2
Reduction Gear Vertical	033901	Log 2
Accessory Gearbox Horizontal	032902	Log 2
No. 5 Bearing Support Vertical	911901	Log 2

Core Bypass Filter
(6 Indications of Vibration)

No. 5 Bearing Support Vertical	911901	Log
Accessory Gearbox Horizontal	032902	Log
Reduction Gear Vertical	033901	Log
Fan Frame Vertical	840901	Log
No. 3 Bearing Support Horizontal	011902	Log
Compressor Aft Flange Horizontal	070902	Log

The above parameters were continuously displayed on the control console immediately adjacent to the engine operator. Readout was directly in mils displacement. In addition, all of the above accelerometers are included in those continuously recorded on Tape Recorder A. Note that each of the "Fan and LPT Tracking Filter" items are each displayed twice, i.e., filtered for fan and LPT frequencies.

Table IV. Control Console Panel Temperature Display.

Temperature Metroscope (50 Channel)

Item	Parameter	Full Data Point	Item	Parameter	Full Data Point
011001	No. 3 Bearing	Log-ADH			
011002	No. 3 Bearing	---	845014	Under Cowl Cavity	Log-ADH
031001	Midspan Bearing Temp.				
032002	AGB Skin				
032004	Aux. Scav Discharge				
033001	Reduction Gear Bearing	Log-ADH			
033002	Reduction Gear Bearing	Log-ADH	845016	Under Cowl Cavity	Log-ADH
033003	Reduction Gear Bearing	Log-ADH			
033004	Reduction Gear Bearing	Log-ADH	845018	Under Cowl Cavity	Log-ADH
033005	Reduction Gear Bearing	Log-ADH	845019	Under Cowl Cavity	Log-ADH
033006	Reduction Gear Bearing	Log-ADH	845020	Under Cowl Cavity	Log-ADH
033007	Reduction Gear Bearing				
033008	Reduction Gear Bearing				
230044	EGT				
323003	Fuel Flow	---	845021	Under Cowl Cavity	Log-ADH
323008	Fuel Manifold	Log-ADH	845022	Under Cowl Cavity	Log-ADH
402003	Lube Supply Pump Inlet				
404003	Scavenge Pump Discharge	Log-ADH	845023	Under Cowl Cavity	Log-ADH
404009	Lube Supply (HX Exit)	Log-ADH			
404011	HX Water Inlet	Log-ADH	911001	No. 5 Bearing	Log-ADH
404012	HX Water Outlet	Log-ADH			
811001	No. 1 Ball Bearing	Log-ADH	911006	Bal. Exhaust Cavity	Log-ADH
811002	No. 1 Ball Bearing	---	911008	No. 6 Seal Air Supply	Log-ADH
812001	No. 1 Roller Bearing	Log-ADH	911012	No. 6 Seal Forward Cavity	Log-ADH
812002	No. 1 Roller Bearing	---	911014	No. 6 Seal Support	Log-ADH
813001	No. 2 Bearing	Log-ADH	911018	Bal. Cavity	Log-ADH
813002	No. 2 Bearing	---	911020	Forward of No. 5 Brg. Support	Log-ADH
845002	Core Cowl Skin	Log-ADH			
845004	Core Cowl Skin	Log-ADH	911022	Aft of No. 5 Brg. Support	Log-ADH
			911030	Aft Sump Scavenge	Log-ADH
845006	Core Cowl Skin	Log-ADH	830003	Slipring Bearing	Log
845008	Core Cowl Skin	Log-ADH	830004	Slipring Bearing	Log

The above parameters were continuously displayed on the control console immediately adjacent to the engine operator. Readout was directly in °F. In addition to the continuous display, all of the above parameters were recorded on ADH each time a full data reading was taken.

Table V. Tape Recorder A - Vibration.

All of the following were continuously recorded as well as displayed on the scopes:

<u>Channel</u>	<u>Parameter</u>	<u>Item</u>
1	Time Code	
2	Core Cowl	006901
3	S/R Accel	830007
4	Fan Frame (V)	840901
5	Fan Frame (H)	840902
6	No. 1 B Bearing (V)	811901
7	No. 1 B Bearing (H)	811902
8	No. 2 Bearing (V)	813901
9	No. 2 Bearing (H)	813902
10	No. 3 Bearing (V)	011901
11	No. 3 Bearing (H)	011902
12	Reduction Gear (V)	033901
13	Reduction Gear (H)	033902
14	C/S Aft Flange (V)	070901
15	C/S Aft Flange (H)	070902
16	No. 5 Bearing (V)	911901
17	No. 5 Bearing (H)	911902
18	Exhaust Cone	231901
19	AGB (A)	032901
20	AGB (H)	032902
21	Digital Control	650901
22	Proximity Probe	033010
23	Proximity Probe	033011
24	IGV Position	-
25	Fan Speed	-
26	Core Speed	-
27	LPT Speed	-
28	Voice	-

Table VI. Tape Recorder B - Fan Blade, Ring Gear and OGV Dynamic Strain Gages.

All of the following were continuously recorded as well as displayed on the scopes:

<u>Channel</u>	<u>Parameter</u>	<u>Item</u>
1	Time Code	
2	Fan Blade (Dynamic Strain Gage)	830801
3	Fan Blade (Dynamic Strain Gage)	830802
4	Fan Blade (Dynamic Strain Gage)	830803
5	Fan Blade (Dynamic Strain Gage)	830804
6	Fan Blade (Dynamic Strain Gage)	830805
7	Fan Blade (Dynamic Strain Gage)	830806
8	Fan Blade (Dynamic Strain Gage)	830807
9	Fan Blade (Dynamic Strain Gage)	830808
10	Fan Blade (Dynamic Strain Gage)	830809
11	Fan Blade (Dynamic Strain Gage)	830810
12	Fan Blade (Dynamic Strain Gage)	830811
13	Fan Blade (Dynamic Strain Gage)	830812
14	Fan Blade (Dynamic Strain Gage)	830813
15	Fan Blade (Dynamic Strain Gage)	830814
16	Fan OGV (Dynamic Strain Gage)	835801
17	Fan OGV (Dynamic Strain Gage)	835804
18	Fan OGV (Dynamic Strain Gage)	835807
19	Fan OGV (Dynamic Strain Gage)	835809
20	Fan OGV (Dynamic Strain Gage)	835811
21	Ring Gear Strain Gage	033801
22	Ring Gear Strain Gage	033802
23	Ring Gear Strain Gage	033803
24	Ring Gear Strain Gage	033804
25	Fan Speed	
26	Core Speed	
27	LPT Speed	
28	Voice	

Table VII. Tape Recorder C - Rake and Fan Frame Dynamic Strain Gages.

All of the following were continuously recorded as well as displayed on the scopes:

<u>Channel</u>	<u>Parameter</u>	<u>Item</u>
1	Time Code	
2	Rake Strain Gage (Inlet)	800801
3	Rake Strain Gage (Inlet)	800802
4	Rake Strain Gage (Inlet)	800803
5	Rake Strain Gage (Inlet)	800804
6	Rake Strain Gage (Boundary Layer)	800810
7	Rake Strain Gage (Strut)	800811
8	Rake Strain Gage (Strut)	800812
9	Rake Strain Gage (Plane 25)	800817
10	Rake Strain Gage (Plane 25)	800819
11	Rake Strain Gage (Plane 25)	800821
12	Plane 25 XPT	840107
13	Plane 25 XPT	840108
14	Plane 25 XPT	840109
15	Fan Frame (Dynamic Strain Gage)	840801
16	Fan Frame (Dynamic Strain Gage)	840802
17	Fan Frame (Dynamic Strain Gage)	840803
18	Fan Frame (Dynamic Strain Gage)	840808
19	Fan Frame (Dynamic Strain Gage)	840813
20	Fan Frame (Dynamic Strain Gage)	840814
21	Fan Frame (Dynamic Strain Gage)	840815
22	Fan Frame (Dynamic Strain Gage)	840816
23	Fan Frame (Dynamic Strain Gage)	840817
24		-
25	Fan Speed	-
26	Core Speed	-
27	LPT Speed	-
28	Voice	-

Table VIII. Sanborn Recorders.

Four Sanborn recorders were used for the initial engine test. The recorded parameters for the first test are defined below:

Sanborn Recorder A

<u>Channel</u>	<u>Parameter</u>	<u>Units</u>	<u>Range</u>
1	Corrected Fan Speed	volts	0 - 10
2	Power Demand	percent	0 - 100
3	PLA	degrees	0 - 150
4	Fan Speed	rpm	0 - 5,000
5	Core Speed	rpm	0 - 15,000
6	IGV Position	degrees	-5 - +75
7	Core Stator Torque Motor Current	mA	± 100
8	---	---	---

Sanborn Recorder B

1	Fuel Flow Torque Motor Current	mA	± 100
2	Main Fuel Flow	lb/hr	0 - 10,000
3	T41C	° F	0 - 3,000
4	Fuel Manifold Pressure	psig	0 - 800
5	Verification Fuel Flow	lb/hr	0 - 10,000
6	T5	° F	0 - 2,000
7	Core Speed	rpm	0 - 15,000
8	T25	° F	0 - 300

Sanborn Recorder C

1	Core Speed	rpm	0 - 15,000
2	AGB Skin Temperature	° F	0 - 250
3	Auxiliary Scavenge Temperature	° F	0 - 300
4	Scavenge Discharge Temperature	° F	0 - 350
5	Lube Pump Discharge Temperature	° F	0 - 200
6	No. 5 Bearing Temperature	° F	0 - 300
7	Oil Tank Level	gal	0 - 25
8	AGB Vent Pressure	psig	0 - 100

Sanborn Recorder D

1	Main Fuel Flow	lb/hr	0 - 10,000
2	Verification Fuel Flow	lb/hr	0 - 10,000
3	Fuel Inlet Pressure	psig	0 - 100
4	Fuel Metering Valve ΔP	psig	0 - 100
5	PS3C	psig	0 - 300
6	---	---	---
7	---	---	---
8	---	---	---

Table IX. Digital Control.

● DIGITAL CONTROL OPERATOR PANEL ON CONTROL CONSOLE

The following parameters are continuously displayed on the Digital Control Operator Panel on the control console directly in front of the engine operator. The displays are in engineering units.

Core Speed	FICA Test No.	Thrust Parameter
Fan Speed	VSV Angle	T41C (T ₃ , P ₃ , W _P)
Power Demand	Inlet Mach No.	T41C (EGT, N _F)

● DIGITAL CONTROL ENGINEERING PANEL (ADJACENT TO CONTROL CONSOLE)

The Digital Control Engineering Panel includes a selectable digital display for any one of the variables listed below. Any one of the 46 may be read out, when selected, in a binary code. The operator of the engineering panel will have equations for each of the parameters to convert them from binary code to engineering units. Each of the following will be recorded by the engineering panel operator whenever an ADH reading is taken:

<u>Thumb Wheel Switch Position</u>	<u>Parameter</u>	<u>Thumb Wheel Switch Position</u>	<u>Parameter</u>
00	VSV Torque Current	24	MVP
01	FICA XNL	25	VSV 1
02	WF TMC	26	VSV 2
03	WF*	27	FICA T3S
04	FICA Test	28	FICA ZWF
05	VSV	29	T3
06	FMP*	30	DWF
07	T41C	31	Mode Word
08	XM11	32	FICA Z8
09	√θ12	33	WF Temperature*
10	Power Demand	34	VSV Instrument. Input*
11	PLA	35	EGT (T56)*
12	N1	36	Engine Oil Inlet Temp.*
13	N2	37	Scavenge Oil Temp.*
14	FICA XNH	38	Engine Oil Inlet Press.*
15	WF MCI	39	Scavenge Oil Press.*
16	Blank	40	T25*
17	Blank	41	P5*
18	F.I.	42	G/B Interrace Bearing Temp.*
19	T12	43	Horizontal Vibration*
20	PTO	44	Vertical Vibration*
21	P14-PTO	45	FICA T56S
22	PTO-PS11	46	FICA PS3
23	PS3		

*Instrumentation Input

Table X. Engine Instrumentation Hookup -Aero Instrumentation.

<u>Item Numbers</u>	<u>Description</u>	<u>Press.</u>	<u>Temp.</u>	<u>Other</u>
<u>Bellmouth Inlet</u>				
005201-005240	(4) Inlet Rakes	20	20	
005254-005260	(1) Boundary Layer Rake	7		
005301-316	Wall Statics	16		
<u>Fan Bypass</u>				
840001-840023	Bypass Duct Statics	23		
840024-840027	Plane 25 Statics	4		
840036-840042	Compressor Inlet Statics	6		
840043-840046	Plane 15 Statics	4		
840201-840230	(6) Compressor Inlet Rakes	30	0	
840231-840235	(6) Compressor Inlet Rakes	0	5	
840246-840250	(6) Compressor Inlet Rakes	0	5	
840256-840260	(6) Compressor Inlet Rakes	0	5	
840107-840109	(6) Compressor Inlet Rakes			(3) Dyn. Press.
<u>Fan OGV</u>				
835201-835208	Island Statics	5		
835209-835220	Vane, Manifolds	12		
835101-835106	Vane Probes	6	0	
835107-835112	Vane Probes	0	6	
<u>Bypass Duct</u>				
006001-006006	Plane 15 Statics	6		
006007-006014	Wall Statics (I.D.)	12		
006101-006219	(7) Arc Radial Rakes	119	36	
006015-006018	Wall Statics (O.D.)	4		
<u>Exhaust Nozzle</u>				
230001-230040	LPT Discharge Rakes	20	20	
230041-230045	Service Strut		5	
230046-230047	Wall statics	2		

The ADH system provided direct telephone communication of data recorded at the Peebles, Ohio test Site to the central computer in the Instrument Data Room (IDR) at Evendale, Ohio. The data was processed, stored, and a short list of averaged and corrected parameters was printed out on the "Quick Look" monitor in the Site 4 control room as an aid in tracking the engine operating conditions. The "Quick Look" parameters are listed in Table XI.

The general layout of the control room, showing locations of the various displays and control panels, is shown in Figure 7.

Table XI. Quick-Look Parameters.

Typewritten output available in the control room from the ADH system for each full data point taken.

<u>Item</u>	<u>Parameter</u>	<u>Units</u>
XNL	Physical Fan Speed	rpm
XNH	Physical HP Compressor Speed	rpm
T2AF	Fan Inlet Temperature	° F
A8	"D" Nozzle Throat Area	in. ²
PCNLR	Percent Corrected Fan Speed	%
PCNHR	Percent Corrected Core Speed	%
WFM	Main Fuel Flow	pph
FAN TORQ	Fan Torque, Calculated	ft/lb
E2AD15	Bypass Duct Inlet Efficiency	---
W2AR	Corrected Fan-Face Total Flow	pps
XM11	Inlet Throat Mach Number	---
W25R	Corrected Core Inlet Air Flow	pps
P3/P25	HP Compressor Pressure Ratio	pps
P15MW/2A	Fan Bypass Pressure Ratio (Mass Weighted)	---
E25D3	HP Compressor Adiabatic Efficiency	---
P21MW/2A	Fan Hub Pressure Ratio (Mass Weighted)	---
T41X	HPTR Inlet Total Temperature (T5, Engergy Balance)	° R
T41XK	HPTR Inlet Total Temperature (T5, Energy Balance Corrected)	° R
FNR	Corrected Thrust	lb
SFCR	Corrected sfc	lbm/hr-lbf
T41C	HPTR Inlet Total Temperature (T3, P3, Wf Digital Control)	° R
E2AD21	Fan Hub Adiabatic Efficiency	---
T55	Exhaust Gas Temperature	° R

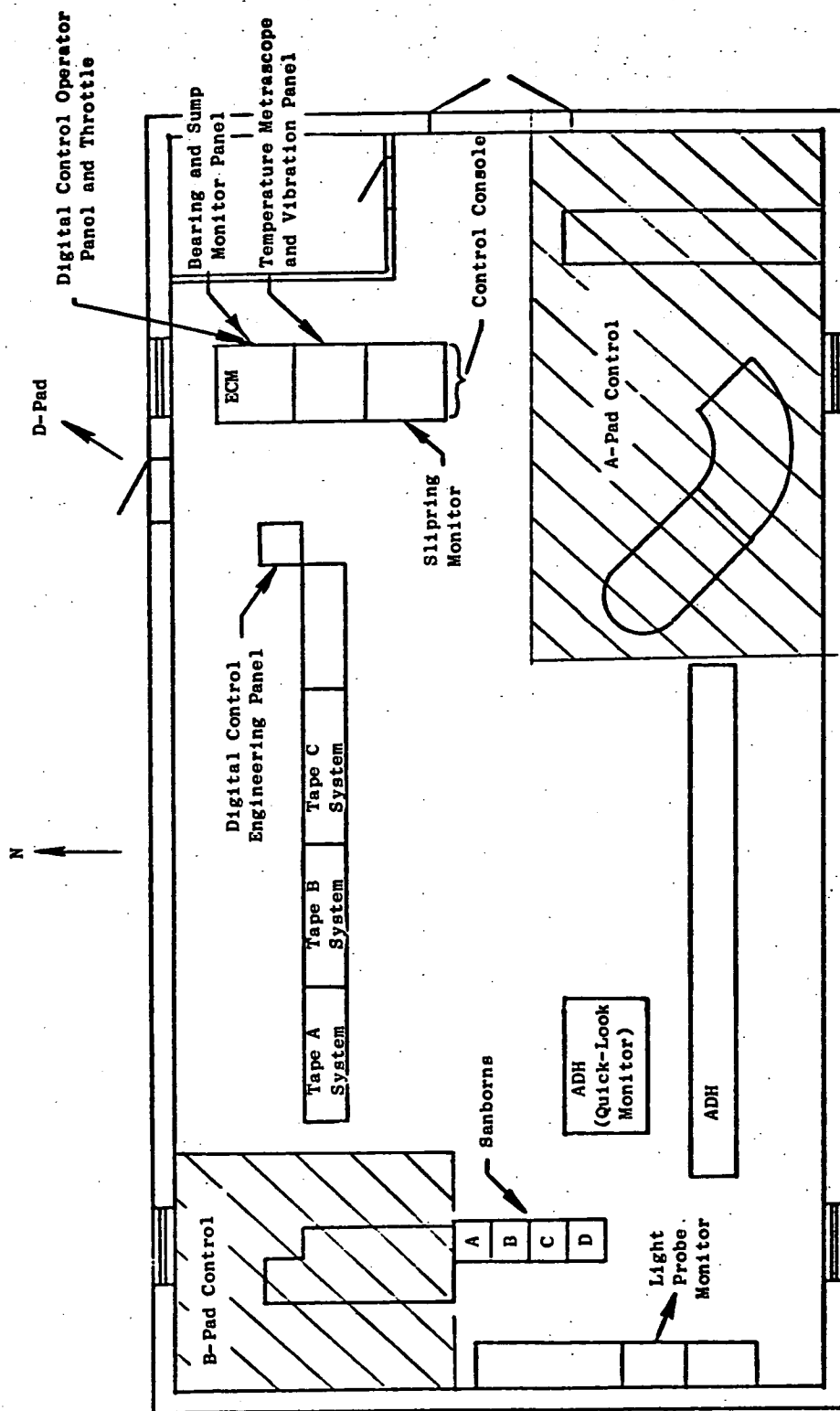


Figure 7. QCSEE OTW Mechanical Checkout Control Room Layout, Peebles Site 4.

6.0 TEST HISTORY

The QCSEE OTW engine, S/N 493-001/1, arrived at the Peebles Test Operation on 3/1/77. The engine, inlet, and "D" nozzle main-mount structures had previously been installed. The fan frame extension, core cowl extension, and core centerbody were installed before raising the engine into the facility. The actual engine installation on the test stand at Site 4D was initiated 3/4/77. The core and fan cowlings, fitted with hard-wall panels, were installed. Minor rework was required to fit-up the panels in the fan door extensions. The core nozzle, nozzle plug, hard-wall bellmouth inlet, "D" nozzle, nozzle transition piece, and instrumentation rakes were installed.

The thrust measuring system was calibrated to 133,440 N (30,000 lbf) simulated forward thrust and 66,720 N (15,000 lbf) simulated reverse thrust. The load cell used (S/N 5724) was a 266,880 N (60,000 lbf) cell with a three-bridge circuit. The closed "D" nozzle cold exhaust area was measured to be 1.562 m² (2433 in.²). The fixed core nozzle area was 0.368 m³ (570 in.²). The engine alternator, fuel control, fuel pump, digital control, variable core stator-vane readout LVDT's, and associated piping were installed. Calibration of the IGV position LVDT's and stage 1 and stage 3 stator-position potentiometers was completed. The slirping system for the fan rotor instrumentation was installed and the connections made. The slirping housing required the usage of dowel pins to prevent excessive runout between it and the spinner. The slave lubrication package was secured to the facility and serviced with 0.166 m³ (44 gal) of Royal 899 oil (MIC-C-23699 Specification). The two oil-level indicators were calibrated at this time.

Instrumentation recording equipment was connected per the Test Request and Test Request Changes (TRC). The recording equipment used is listed below:

<u>Item</u>	<u>Serial Number</u>
Digital	60953
Sanborn A	4951
Sanborn B	4953
Sanborn C	4952
Sanborn D	4954
Tape Recorder A	2092
Tape Recorder B	2087
Tape Recorder C	4920

On March 30, 1977, the engine and facility pretest checklist was completed in preparation for the initial dry and wet motoring. The engine was motored at 3500 rpm core speed for four minutes with no oil leakage; however, fuel vapors were visible in the core exhaust. Investigation showed that the throttle had not been rigged properly. The throttle was readjusted using the digital control to verify the fuel-control metering-valve position. A wet motor at 3500 rpm core speed for three minutes was performed with no oil or fuel leaks evident.

The right-hand core door was locally reworked to relieve an interference between the door and the stator position LVDT bracket. The lube system was serviced with 0.025 m³ (6.5 gal) of Royal 899 oil to replace the oil "gulped" by the engine and service lines during the two motors. The engine and test pad were then secured for the first engine fire-to-idle. The following is a history of the test and related significant events while the QCSEE OTW engine was on test between 3/31/77 and 6/9/77. All reference data (thrusts, speeds, lube level, etc.) is as recorded from the control panel instruments in the control room. The initial test configuration is shown in Figure 8.

Events Prior to Run No. 1

On 3/31/77, several unsuccessful attempts were made to obtain idle. In each instance the engine would light, but would not self-sustain in the sub-idle region (7000-8000 rpm core speed). Several upward adjustments on the accel schedule were made, up to 20% of nominal, with no appreciable effects. Two and three relights were obtained on the last several aborted starts by applying continuous ignitor operation. Further attempts to fire-to-idle were suspended until additional diagnostic instrumentation could be added to the fuel system. Maximum core speed obtained was 10,060 rpm, slightly less than estimated idle speed. No other problems were evident as all engine operating parameters were satisfactory.

Prior to the next fire-to-idle attempt, the following instrumentation was added:

- Fuel Control Metering Valve ΔP
- Fuel Pump Discharge Pressure
- Close-Coupled PS3
- Close-Coupled, Fuel-Manifold Pressure
- Fuel Flowmeter Downstream of Fuel Control
- Two High Response EGT Thermocouples

The facility fuel supply line was purged of 0.379 m³ (100 gal) of fuel in an attempt to flush suspected air out of the system. A wet motor was performed with the fuel control port (PCR), fuel manifold port, and the tap downstream of the fuel metering valve open to bleed air out of the engine fuel lines. These lines were reconnected while the PS3 line to the fuel control was capped. A fault in the slave throttle system was discovered and corrected at this time.

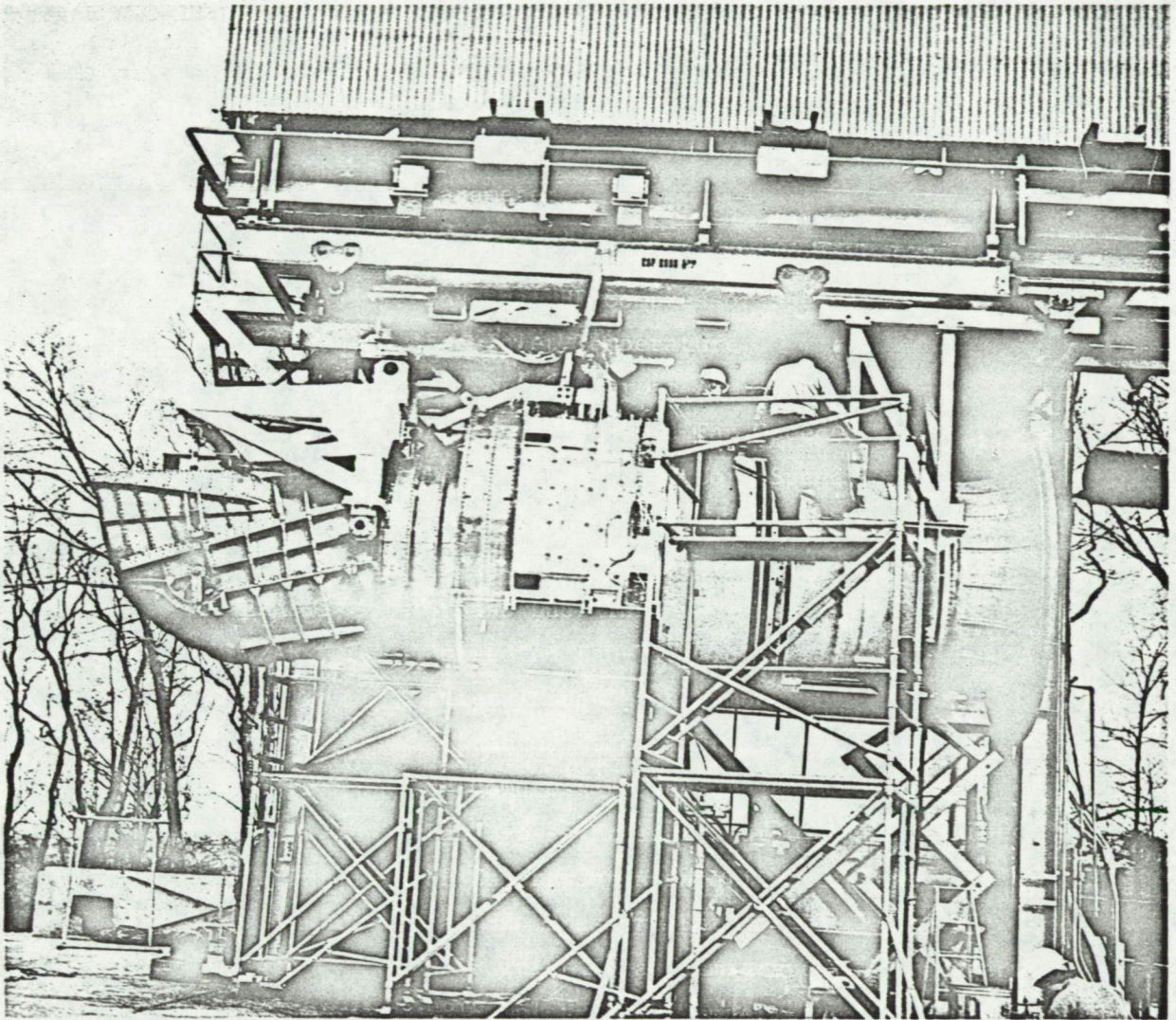


Figure 8. Initial OTW Engine Configuration.

Engine Starts No. 1 Through No. 3

On 4/4/77 a wet motor was performed followed by two successful fire-ups-to-idle. Idle speeds stabilized at 1319 rpm fan and 10,300 rpm core. The acceleration time from 4000 to 10,300 core rpm was approximately 32 seconds, characterized by a "soft" light. The reduction gear accelerometers were very active, suggesting that an adjustment in the engine idle speed was required. The engine was shut down shortly after idle was achieved for both starts, and further running was suspended until after arrival of all engine monitors. The additional downstream fuel flowmeter was removed and the original engine piping restored.

On 4/5/77, the engine was fired uneventfully to idle; however, a sudden snow squall forced a shutdown almost immediately. Subsequent snow showers prevented further testing that day. Total engine run time was 5 minutes and ADH readings 1 through 3 had been taken. The A8 side flap angle was 17.3° for all three starts.

RUN: No. 1 - Mechanical Checkout
DATE: 4/6/77
RUN TIME: 55 Minutes
TOTAL ENGINE RUN TIME: 1 Hour, 0 Minutes
ADH READINGS: No. 4 through 10

The engine was fired-to-idle without incident. The idle speed was adjusted up to 10,900 rpm core speed, 1780 rpm fan speed, to avoid high vibration activity from the reduction gear support accelerometers. The oil level indicator recorded a drop from 0.057 m^3 (15 gal) to 0.042 m^3 (11 gal) during the start and remained steady. ADH and engineering panel readings were taken at idle, with no engine problems discovered. After a 10-minute stabilization at idle, mechanical checkout continued.

Panel and ADH readings were recorded at 1865 (50%), 2429 (65%), and 2610 (70%) rpm corrected fan speed. A steady decline in the oil level had been recorded at each speed point, until only 0.0076 m^3 (2 gal) of oil was being indicated. The engine was shut down to investigate the origin of the oil leakage.

As the engine was coasting down from idle, a large quantity of oil ran out from under the core doors and out of the "D" nozzle exhaust. Subsequent inspections found evidence of oil leakage in the core pylon area, although no definite leak path was found. Oil line fittings in this area were checked; none were found loose. Two dry motors to 3500 core rpm were performed with the cowl doors open, but the leak could not be isolated. Further testing was suspended until an action plan could be formulated.

Engine operation parameters for the run were quite satisfactory. There appeared to be no balance or lube system problems. A slight fan blade stress was encountered at 2233 fan rpm, but was not excessive. Maximum speeds

reached were 2793 rpm (75%) fan and 12,020 rpm core. Total oil loss in Run No. 1 was 0.023 m³ (6 gal).

RUN: No. 2 - Mechanical Checkout
DATE: 4/14/77
RUN TIME: 35 Minutes
TOTAL ENGINE RUN TIME: 1 Hour, 35 Minutes
ADH READINGS: No. 11 through 12

Prior to this run, the engine was steam cleaned and the lube system serviced with 0.042 m³ (11 gal) of Royal 899. Several dry motors were performed, enabling the oil leakage to be traced to the upper end of the radial drive shaft midspan bearing housing. A portion of the pylon wall was removed, and the leak was further isolated to the area where the drive shaft sleeve joins the metal cup at the base of the accessory gearbox.

Following an extensive cleaning operation, the area at the top of the midspan bearing housing and drive shaft sleeve/gearbox cup interface was sealed with Furane epoxy. After a dry motor, an additional leak was discovered around the lube supply line penetration at the 10 o'clock fan frame strut. This and the 12 o'clock strut (where the drive shaft penetrates the sump wall) were also sealed with Furane. A subsequent dry motor did not reveal any evidence of an oil leak. The access hole in the pylon skin, used in the Furane sealing operation, was repaired, the nozzle side doors adjusted to 11.5°, and the engine prepared to run.

The purpose of Run No. 2 was to determine if the Furane sealing operation was successful in controlling the oil leak. Engine starts 6 and 7 were aborted due to loss of core speed and EGT. Start No. 8 was successful, and the engine was stabilized at idle for a period of 30 minutes during which time approximately 0.004 m³ (1 gal) of oil was lost. Traces of oil were visible along the outside of the fan frame OGV's and the core doors. The engine was shut down, steam cleaned, and fired back to idle for a five-minute diagnostic run to attempt to discover the source of this leak. Results of this run were:

1. No trace of leakage from the accessory area.
2. No trace of oil between the forward and midwheels of the fan frame.
3. Oil was running along the left side of fan frame under the core cowl just aft of the midwheel.
4. No trace of oil under the core cowl on the right-hand side of the engine.
5. No trace of oil leakage from engine piping.

This completed Run No. 2, as preparations were made to helium-leak check the fan frame.

RUN: No. 3 - Mechanical Checkout
DATE: 4/20/77
RUN TIME: 34 Minutes
TOTAL ENGINE RUN TIME: 2 hours, 9 Minutes
ADH READINGS: No. 13 through 14

Prior to this run, an extensive leak check was performed. The forward sump and accessory gearbox were isolated and pressurized with 6.9 kN/m^2 (1 psig) of helium, and a helium detector was used to check for possible leak paths. A positive leak was detected beneath the accessory gearbox in the pylon area using this method. Oil was then pumped into the accessory gearbox, creating a flooded condition, through the auxiliary scavenge line by reversing the motor on the auxiliary pump. Oil was visible as it escaped from the fan-frame, acoustic treatment on either side of the pylon. Sighting through access holes cut into pylon side walls, oil was seen running down the inside pylon wall between the drive shaft sleeve and the forward face of the aft wheel.

A section of the fan-frame, outer skin on both sides near the accessory gearbox was removed; this uncovered an unexpected cavity, in a pocket of adhesive, filled with oil. The cavity extended through the adhesive, underneath the cup which supports the accessory gearbox, and ran along the entire length. Extensive rework to the fan-frame, outer skin was required to gain better access to this cavity. The gearbox was again flooded, and oil was seen leaking freely from the aft underside of the cup/drive shaft sleeve interface.

Further rework to this area was completed to open up any other cavities that may have existed. The area was cleaned thoroughly and encapsulated entirely with Furane epoxy. The entire pylon, down to the top of the midspan bearing housing, was also filled with Furane.

An extensive helium-leak check and three deliberate floodings of the accessory gearbox followed with no indication of any leakage. A three-minute, dry motor with the core doors open also disclosed no visible oil leaks. The core cowl doors were closed and the engine was prepared to run.

The purpose of run No. 3 was to verify that the second Furane-sealing operation succeeded in controlling the oil leakage. The fan cowl doors remained open, providing a better view of the leakage area.

Engine starts No. 10 and 11 resulted in flameouts after approximately 30 seconds at idle. Idle was obtained with start No. 12. After running at idle for 30 minutes, the oil level indicator did not register any decline. The engine was shut-down and inspected; no evidence of oil leakage was discovered. This concluded Run No. 3, and the engine was prepared for continuation of mechanical checkout.

RUN: No. 4 - Mechanical Checkout
DATE: 4/21/77
RUN TIME: 6 Hours, 35 Minutes
TOTAL ENGINE RUN TIME: 8 Hours, 44 Minutes
ADH READINGS: No. 15 through 40

The purpose of the run was to complete mechanical checkout and aerodynamic performance mapping up to 100% corrected fan speed. The lube system was serviced with 0.030 m³ (8 gal) of Royal 899 oil prior to the start, bringing the lube level indicator to 0.079 m³ (21 gal).

Engine start No. 13 was uneventful. ADH and panel readings were recorded at idle, 1905 (50%), and 2677 rpm (70%) fan speed. A fluctuation in the oil level indicator between 0.045 m³ and 0.053 m³ (12 to 14 gal) while setting the 80% speed point was cause for immediately decelerating the engine to idle, where the lube level indication stabilized at 0.025 m³ (6.5 gal). An idle inspection identified an oil leak in the slave lubrication package. The engine was stop-cocked and the following action taken:

- Repaired a faulty connector on the lube level sensor.
- Switched the control panel oil level indicator to read the secondary level sensor in the tank.
- Replaced "sandwich" type gasket on top of the main oil tank.

The next engine start was aborted due to no fan rotation. The fan was rotated two revolutions by hand to relieve any seal seizure. The test resumed with engine start No. 14.

This test included performance mapping of three operating lines covering the full range of fan nozzle flap settings (0°, 11.5°, and 25°). The fan nozzle hot areas tested were 1.577, 1.720, and 1.90 m³ (2444, 2666, and 2947 in.²). The engine-vibratory and fan-blade-aeromechanical characteristics within the operating envelope tested were quite satisfactory with no restrictions upon engine operation imposed. Maximum speed achieved was 3813 rpm fan at 13,772 rpm core speed. Maximum indicated thrust obtained was 84,200 N (18,930 lbf) with 25° nozzle flap angle at 95% fan speed.

The digital control performed well throughout the test, holding fan speed to within ±0.2% of the selected value. Both T41C and T5 limits restricted operation above 99% fan speed (3813 rpm) with the nominal "D" nozzle area (11.5° flap setting) and above approximately 95% speed with the full open and closed "D" nozzle areas. The aft, undercowl-cavity temperatures went over the 589 K (600° F) limit at top speeds, but the core-cowl-skin temperatures remained within limits and did not affect the test.

The lubrication and scavenge system functioned satisfactorily. The lube supply inlet temperature was held to a maximum of 333 K (140° F). All bearing temperatures were well behaved, although the midspan bearing housing ran slightly hotter than expected. The Furane-sealing operation effectively controlled oil loss; although oil consumption was high (approximately 0.023 m³ (6 gal) in 6 hours and 35 Minutes), this was not considered to be a hindrance to the continuation of the planned test program. The maximum oil scavenge and auxiliary scavenge temperatures were 423 K (301° F) and 404 K (268° F) respectively. Both T5 and T41C ran approximately 28 K (50° F) hotter than expected.

The ring gear strain gages and reduction gear Bently proximity probes were lost during the test. The postshutdown inspection revealed only a small puddle of oil lying in the fan bypass duct directly aft of the fan frame at 6 o'clock. No other evidence of oil leakage was discovered. The engine-mounted scavenge screen was removed, and small particles of Ren-Weld epoxy and strain gage lead wire, apparently from the ring gear instrumentation, were found. A borescope inspection of the engine revealed nothing unusual. This completed mechanical checkout with the bellmouth inlet, and the configuration was changed for the baseline acoustic test.

RUN: No. 5 - Baseline Acoustic Test
DATE: 4/29/77 and 4/30/77
RUN TIME: 10 Hours, 34 Minutes
TOTAL ENGINE RUN TIME: 19 Hours, 18 Minutes
ADH READINGS: No. 41 through 70

The purpose of this test was to establish a baseline acoustic measurement with the hard-wall nacelle and bellmouth inlet. This test involved far more acoustic instrumentation than had previously been used in any one engine test. Prior to the test, the following configuration changes were made:

- Removed slipring and slipring strut and installed spinner cap.
- Removed four inlet rakes, one boundary layer rake, seven fan bypass rakes, and eight LPT discharge rakes and installed the respective blankoff pads.
- Installed acoustic traverse probes at the fan face, fan OGV discharge, and core exhaust.
- Installed three vortex-degenerator fans in front and to the right side of the fan inlet.
- Set up near-field, far-field, and ground-plane microphones and the acoustic array per the Test Request.
- Installed four wall dynamic pressure sensors in the fan bypass duct doors and two sensors in the bellmouth inlet.

- Revised tape recorders A, B, and C and Sanborns A and B per Test Request Changes for the acoustic test.
- Repaired inlet bulb seal with RTV to prevent seal from protruding into the flow stream.
- Adjusted "D" nozzle flaps to 11.5°.

Prior to starting the engine, the following baseline, far-field, sound data were recorded:

1. Background noise, all facility items off.
2. Auxiliary scavenge pump on only.
3. Digital Control cooling air on only.
4. Undercowl cooling air on 1/2 capacity.
5. Undercowl cooling air on, full capacity.
6. Vortex-degenerator fans on only.
7. All systems on, including full undercowl cooling air.

The engine was fired-to-idle without incident. Panel and ADH readings, plus far-field, near-field, and wall dynamic pressure acoustic data were recorded at "D" nozzle flap settings of 0°, 11.5°, and 25°. An evaluation of the three vortex fan degenerators was conducted early in the test with the flap angle set at 11.5°. The fans eliminated the ground vortex; however, no significant change in the noise level was observed at the approach power setting. The fans were not used for the remainder of the test. Completion of the far-field, acoustic testing was completed after 4 hours and 47 minutes, and the engine was shut down to calibrate the acoustical-array microphones.

During the shutdown, an inlet and tail-pipe inspection revealed the following:

- Small amount of oil accumulated in the core inlet (apparently leakage from the No. 1 seal).
- Very small amount of oil dripping out from under the core doors.
- The aft-most core cowl latch was damaged, allowing the hand-release lever to protrude into the fan stream.

The following action was taken before restarting the engine:

- Repaired broken core cowl latch with RTV, securing hand-release lever out of the fan stream.

- Adjusted "D" nozzle side flaps to 11.5°.
- Serviced lube system with 0.030 m³ (8 gal) of Royal 899, bringing the indicated lube level back to 0.079 m³ (21 gal).

The test was resumed with engine start No. 17. Acoustic-array data were taken at 97.5% (3655 rpm) fan speed (this being the top speed dictated by the T41C limit) at five different aiming points (120°, 110°, 100°, 80°, and 60°). High undercowl cavity and skin temperatures were encountered at this speed, requiring the engine to be decelerated to 80% (3000 rpm) fan speed between aiming points to allow it to cool. The "D" nozzle flaps were adjusted to 25°, and the array data was repeated at approach, 81% (3033 rpm) fan speed.

After 1 hour and 47 minutes of array testing, the engine was shut-down to prepare for taking acoustic traverse probe data. During this run, the lube level indicator recorded a 0.015 m³ (4 gal) drop in oil level.

The core traverse probe was readied and the test continued with start No. 18. The fan face, fan OGV exit, and core exhaust acoustic probes were traversed at 95% (3640 rpm) fan speed, 11.5° flap angle and 81% (3087 rpm) fan speed at 25° flap angle. The 95% speed point corresponded with the T41C limit. The core probe was traversed at the lower center and outside position. No core data were taken at the upper center position due to a loss in the Kulite sensor signal as the probe was traversed. During the test the lubrication system and the digital control continued to perform well. Engine speed was again limited by T41C. Maximum speed achieved during the test was 3721 rpm (99.4%) fan speed at 13,509 rpm core speed with the "D" nozzle flaps set at 11.5°. Total engine running time included 2 hours and 5 minutes at or above 95% fan speed and 40 minutes at or above 97% fan speed. Total amount of oil consumed was 0.057 m³ (15 gal). The postshutdown inspection indicated no evidence of significant oil leakage. This completed Run No. 5.

RUN: No. 6 - High Mach Number Inlet Performance Test
 DATE: 5/5/77
 RUN TIME: 2 Hours, 41 Minutes
 TOTAL ENGINE RUN TIME: 21 Hours, 59 Minutes
 ADH READINGS: No. 71 through 84

The purpose of this test was aerodynamic performance testing with the high Mach number inlet. The following configuration changes were performed prior to the test:

- Installed high Mach number inlet with all hard-wall panels.
- Removed acoustic probes and installed all aerodynamic performance rakes, slipring, and slipring strut.
- A borescope inspection of the engine was completed, and the scavenge screen was removed and cleaned. The screen had collected the same type of residue as in the previous test.

- Replaced lower section of inlet bulb seal that was damaged during removal of bellmouth inlet.
- Cleaned surface of fan blades and spinner.
- Raised limit of aft undercowl cavity thermocouples to 644 K (700° F).
- Serviced lube system with 0.030 m³ (8 gal) of Royal 899 oil.

The configuration for this test is shown in Figures 9 and 10. On the initial start, the water flowmeter to the slave oil/water heat exchanger registered zero flow. The engine was stop-cocked after 15 minutes of running at idle when the lube supply inlet temperatures exceeded 336 K (145° F). The problem was traced to the facility water-supply line and corrected.

The test resumed with engine start No. 23. Fourteen data points were taken which provided performance and aeromechanical data at takeoff, cruise, and approach conditions. The engine was operated to 97% speed (3693 rpm fan and 13,500 rpm core), with a maximum indicated thrust of 81,398 N (18,300 lbf) at a nozzle flap setting of 25°. The digital control and lube system performed well throughout the test.

High fan filtered vibrations were observed near 81% fan speed (3100-3200 rpm) with the nozzle flaps set at 25°. The oil-level indicator first registered a steady decline in oil level at 95% speed (3620 rpm) at a rate of approximately 0.004 m³ (1 gal) every 10 minutes. This high oil consumption was repeated thereafter for speeds in excess of 90% fan speed (3430 rpm).

The low lube level light illuminated while setting the final high speed point, 97% fan speed (3690 rpm), as the indicator showed 0.011 m³ (3 gal) of oil. After shutdown, the oil level recovered to 0.051 m³ (13.5 gal). Total amount of oil consumed during the test was 0.028 m³ (7.5 gal). The posttest inspection showed no unusual evidence of oil leakage. Total run time was 2 hours and 41 minutes of which 1 hour and 30 minutes was above 90% speed and 49 minutes was above 95% speed. This concluded Run No. 6.

RUN: No. 7 - Reverse Performance Test
 DATE: 5/9/77 and 5/10/77
 RUN TIME: 3 Hours, 42 Minutes
 TOTAL ENGINE RUN TIME: 21 Hours, 59 Minutes
 ADH READINGS: No. 85 through 106

The purpose of this run was performance and aeromechanical testing in the reverse-thrust mode. Prior to the test, the following configuration changes were made.

- Installed inlet reingestion shield
- Opened nozzle blocker door to the 115° turning-angle position.

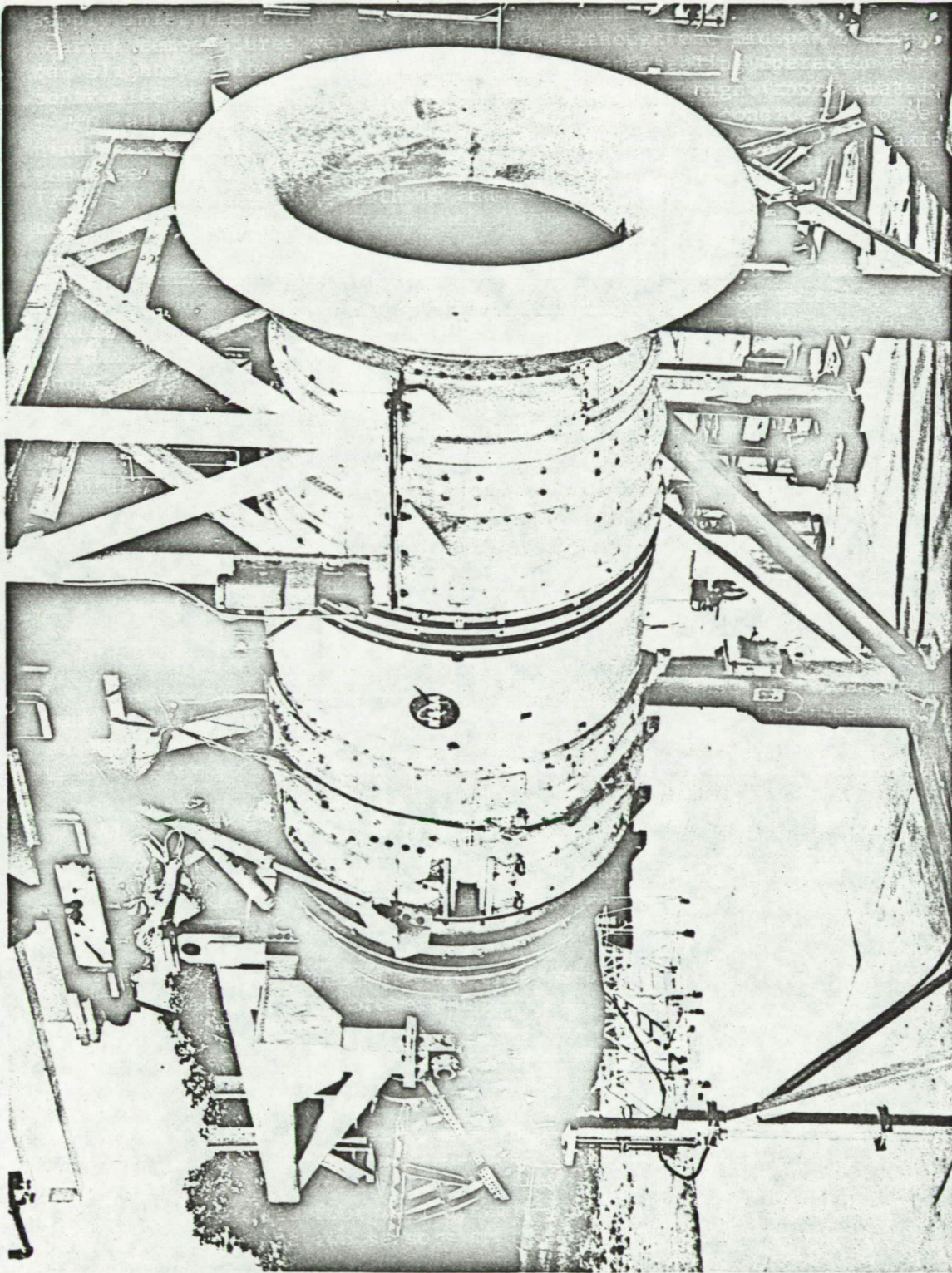


Figure 9. QCSEE OTW Engine Test High Mach Number Inlet Configuration.

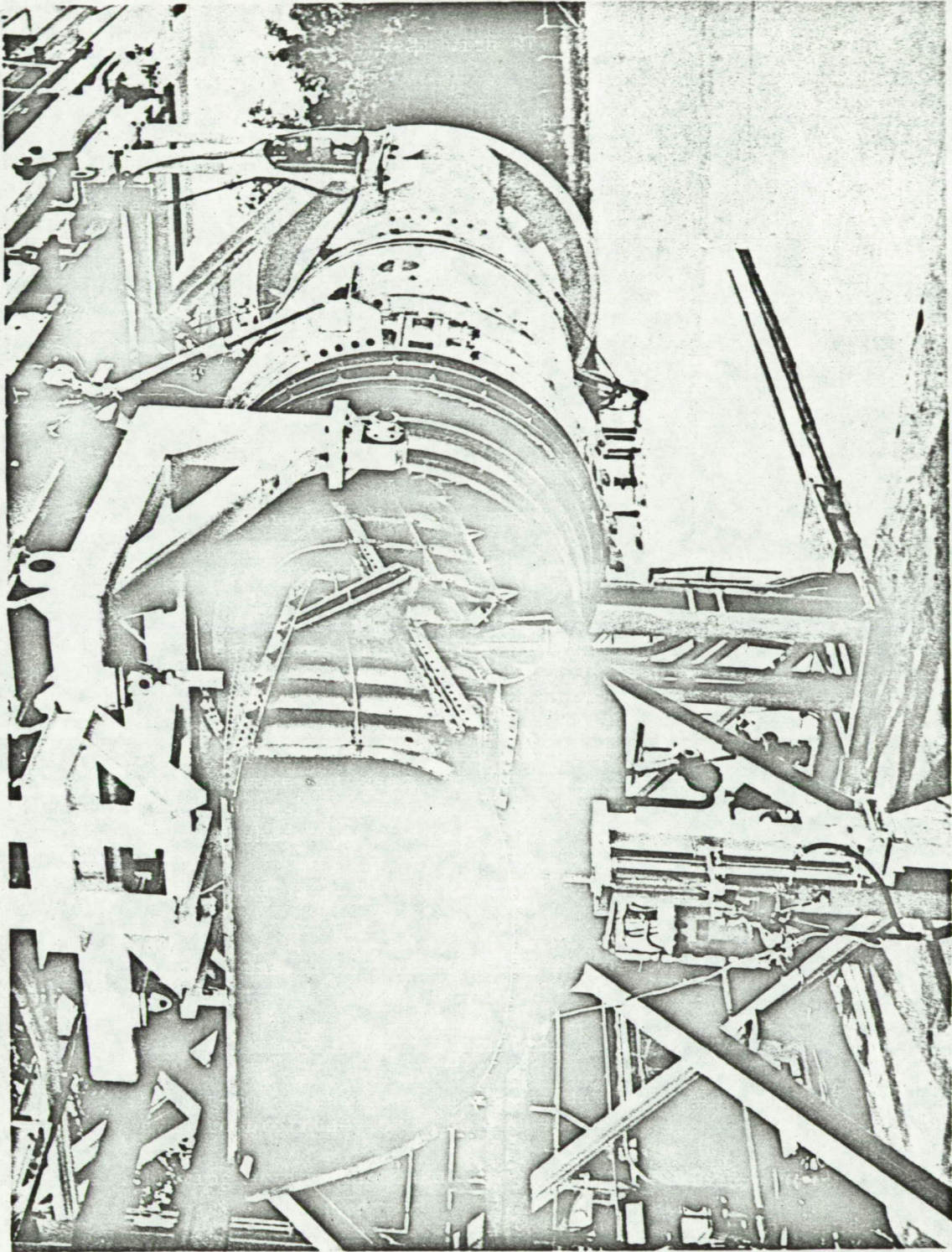


Figure 10. QCSEE OTW Engine Test High Mach Number Inlet Configuration.

- Installed nozzle side skirts and 0.6 reverser lip extension. Side flaps were adjusted to 0°.
- Serviced lube system with 0.030 m³ (8 gal) of Royal 899 oil

The reverse-thrust test configuration is shown in Figures 11 and 12. The engine was fired-to-idle, but high fan blade stresses due to approaching instability at approximately 45% fan speed forced an immediate shutdown; however, the blade stresses did not exceed 50% of scope limits. The nozzle side flaps were opened to 25°, thus increasing the nozzle exit area, and the engine was again fired-to-idle, this time with no blade stress problems. The idle check disclosed that the facility fuel supply line was directly in the nozzle exhaust blast area and was subjected to excessive movement. The engine was shut-down, and a blast shield of concrete blocks was installed between the nozzle exhaust and the facility service lines. The nozzle side flaps were adjusted to 11.5°, and the engine was fired-to-idle without incident. Panel and ADH readings were taken up to 77% fan speed (2939 rpm) at an indicated reverse thrust of -28,423 N (-6390 lbf). Further testing at this time was suspended until the concrete blocks making up the blast shield could be secured further. Total run time for this portion of the test was 1 hour and 15 minutes.

Additional tie-down cables were installed both to the concrete blocks and to the inlet reingestion shield. The engine test then resumed with engine start No. 27. Maximum indicated reverse thrust achieved was -37,100 N (-8340 lbf) at 86% fan speed (3316 rpm). The aft undercowl skin temperatures went slightly over limit at the higher speeds, requiring a cooling-off period at a lower power setting between these data points. Total run time for the 115° turning-angle blocker door configuration was 2 hours and 26 minutes.

The nozzle blocker door was changed to the 105° turning-angle position and side flaps were adjusted to 0°. No blade-stress problems were encountered as the engine was fired-to-idle. Six full data points were taken. Maximum indicated reverse thrust was -36,900 N (-8300 lbf) at 83.6% fan speed (3242 rpm); this was the maximum speed obtained as dictated by the T41C limit of 1600 K (2420° F). The aft undercowl skin temperatures continually ran above limits at the higher power settings; thus, returning the engine to idle was required between data points. This portion of the test lasted 1 hour 17 min.

The digital control and lube system continued to work well. The aft sump cooling air used for UTW reverse testing was not required. Maximum fan speed obtained for the entire test was 86.2% (3316 rpm). The engine operation throughout the test was quite satisfactory; no oil was consumed. This concluded the reverse-thrust performance testing.

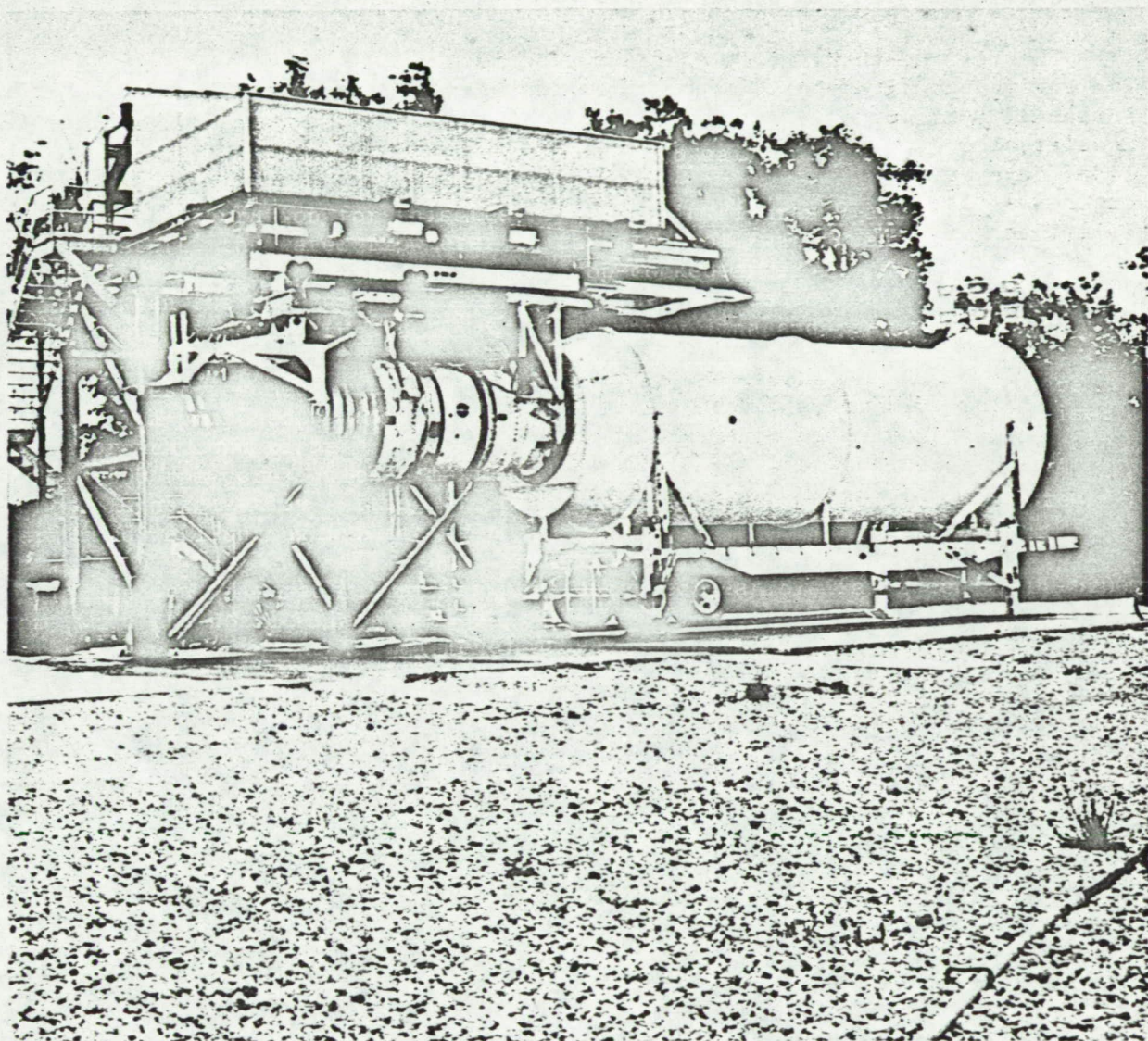


Figure 11. Inlet Reingestion Shield Installation.

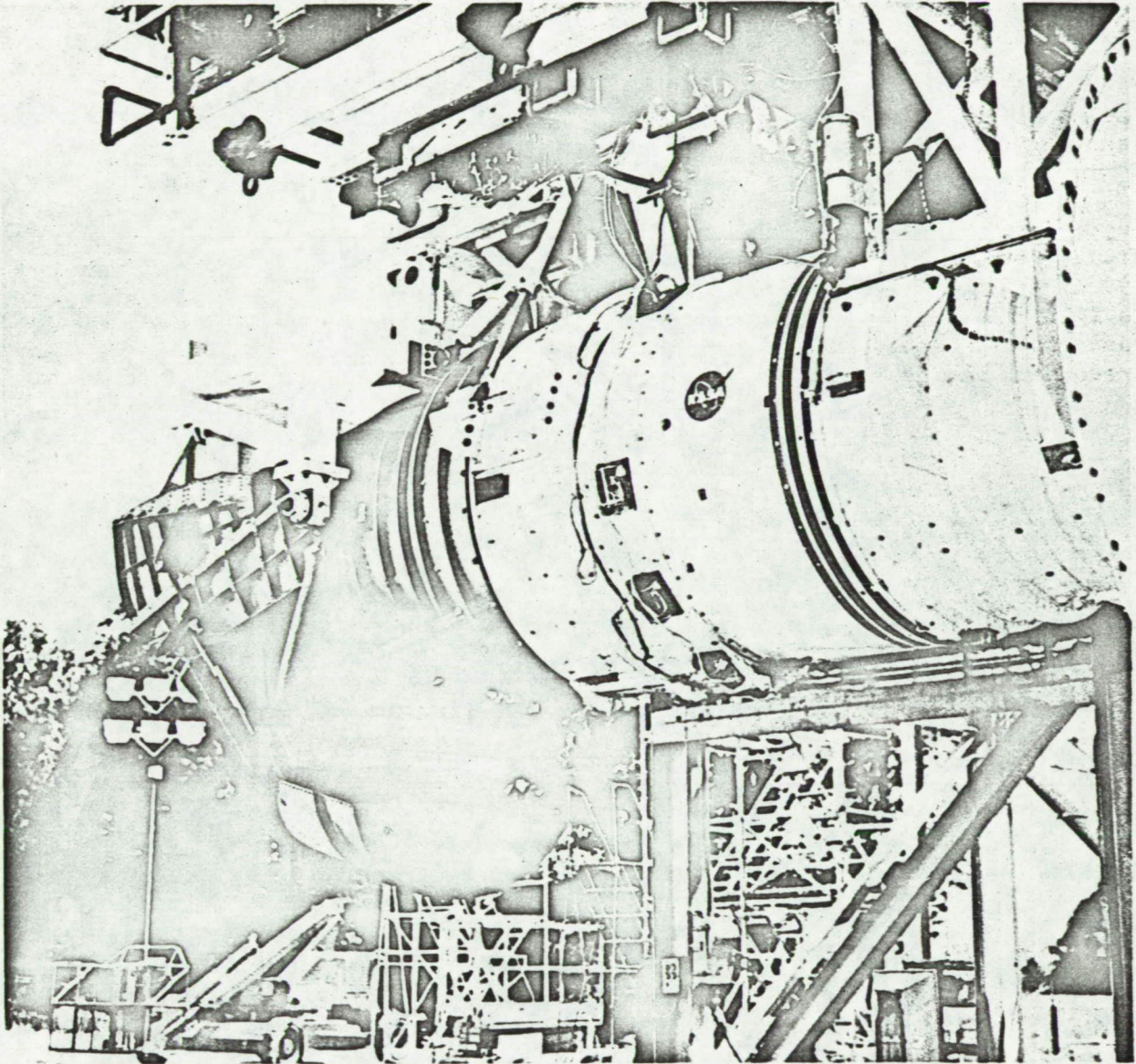


Figure 12. QCSEE OTW "D" Nozzle in Reverse-Thrust Position.

RUN: No. 8 - Inlet Reingestion Shield Performance Check
DATE: 5/10/77
RUN TIME: 1 Hour, 37 Minutes
TOTAL ENGINE RUN TIME: 27 Hours, 18 Minutes
ADH READINGS: No. 107 through 116

The purpose of this test was to run a performance-effect test while using the reingestion shield. Prior to the run, the nozzle was returned to the forward-thrust configuration and the side flap angle adjusted to 0°.

The engine was fired-to-idle without incident. ADH and panel readings were taken at idle, 90%, 95%, and maximum allowable fan speed (as limited by T41C), at 0° and 11.5° side flap angles. Maximum fan speed achieved was 99.1% (3711 rpm). Although the aft undercowl cavity temperatures went slightly above limits at high speeds, the skin temperatures were well behaved and did not affect the running of the test. Again no loss in oil level was recorded. The postshutdown inspection showed nothing unusual.

RUN: No. 0 - Reverse Fully Suppressed Acoustic Test
DATE: 5/18/77
RUN TIME: 4 Hours, 0 Minutes
TOTAL ENGINE RUN TIME: 31 Hours, 18 Minutes
ADH READINGS: No. 117 through 127

The purpose of this test was to run the fully suppressed, reverse-thrust, acoustic test. Prior to the test the following configuration changes were made:

- Opened blocker door to the 105° turning-angle position.
- Set side flaps at 0°.
- Removed the hard-wall, core nozzle and nozzle centerbody and installed the acoustically treated core nozzle and centerbody.
- Installed the one-meter (40 in.), fan-duct, acoustic splitter.
- Removed hard-wall acoustic panels from the inlet, fan, and core doors. Installed single-degree-of-freedom (SDOF) acoustic panels in the fan and core doors and Kevlar panels in the inlet.
- Removed all aeroperformance instrumentation, slirring, and slirring strut.
- Installed acoustic traverse probes at the fan face and fan duct OGV discharge.
- Installed seven wall Kulites in the inlet and four in the fan doors.

- Set up far-field, near-field, and ground-plane microphones per Test Request.

The hard-wall, core-cowl panels were visually inspected for damage resulting from excessive heat as the panels were removed; no damage was found. The noise level of the undercowl cooling air system was measured using a hand-held, noise meter prior to the test per Acoustic Evaluation's request. Each source of cooling air was measured individually and then collectively both at half and at full capacity. During the pretest inspection, several small nicks were found on the leading edges of the metallic fan outlet guide vanes, none of which were considered severe. Oil level prior to the start of the test was 0.070 m³ (18.5 gal).

The engine was fired-to-idle, but was shut-down shortly thereafter when the idle inspection found electrical leads from the fan OGV acoustic probe being whipped about by the nozzle exhaust. After securing the leads, the test resumed with engine start No. 31. A total of 19 sound readings were taken at nine different speed points. This included far-field, near-field, and ground-plane microphones, wall kulites, two acoustic traverse probes, and acoustic-array data as well as panel and ADH readings.

The engine operation was good throughout the test with no temperature, vibratory, or blade stress problems. The digital control and lube system continued to perform well. Maximum speed tested was 80.7% (3198 rpm fan and 13,330 rpm core). Maximum indicated thrust was -35,140 N (-7900 lbf). Oil consumption for the test was 0.015 m³ (4 gal). The postshutdown inspection revealed nothing unusual. This concluded run No. 9.

RUN: No. 10 - Fully Suppressed Forward Acoustic Test
 DATE: 5/20/77
 RUN TIME: 7 Hours, 23 Minutes
 TOTAL ENGINE RUN TIME: 38 Hours, 41 Minutes
 ADH READINGS: No. 128 through 151

The purpose of this test was to run the fully suppressed, forward-thrust, acoustic test. Prior to the test, the following configuration changes were made:

- Removed the inlet reingestion and concrete block blast shields.
- Returned the nozzle blocker door to the forward-thrust configuration and adjusted side flaps to 11.5°.
- Installed additional acoustic traverse probes in the inlet throat and core exhaust.
- Serviced lube system with 0.015 m³ (4 gal) of Royal 899 Oil.

Based on the information derived from the hand-held noise meter prior to the previous test, an alteration to the undercowl cooling system was required. Noise levels in the forward and aft undercowl cavities were excessively high

because of the "dump" type cooling air lines being used. The following changes were made:

1. Because the forward undercowl cavity temperatures had been well behaved during all previous tests, the single "dump" cooling air line in this cavity was deleted. The two manifolded lines supplying the core cowl panels with cooling air remained.
2. The two "dump" type cooling air lines in the aft cavity were deleted because their effectiveness in cooling the aft core cowl panels was limited. They were replaced with a single cooling manifold routed circumferentially around the engine, ejecting cooling air directly on the aft panels.

The first start was aborted when the digital control failed to come into regulation; however, the second attempted start was successful. The test consisted of 47 sound readings and 23 ADH data points covering cruise, approach, and takeoff power settings with side flaps angles of 0°, 11.5°, and 25°. Readings were also taken with 5° and 10° closed core stator vane adjustments. Sound readings at speeds below 80% were taken with the undercowl cooling air turned off; higher cowl skin temperatures at higher speeds dictated the use of cooling air. All planned testing, including the acoustical array, was completed except for the core exhaust traverse probe data. A failed dynamic pressure sensor terminated the probe usage late in the test.

The aft undercowl skin temperatures were slightly lower than in previous tests, indicating that the added cooling manifold was working well. The deletion of the three "dump" type cooling lines had no adverse effects on the undercowl temperatures. Maximum speed tested was 97.3% (3698 fan rpm) which was at the T41C limit. The lube system was serviced with 0.026 m³ (7 gal) of Royal 899 oil at 35 hours 35 minutes. After the test the system was serviced with 0.053 m³ (14 gal) of Royal 899, making oil consumption for the test 0.079 m³ (21 gal). Engine and digital control performance was satisfactory throughout the test. The postshutdown inspection showed nothing unusual.

RUN: No. 11 - Hardwall Accelerating Inlet Acoustic Test
DATE: 5/23/77 and 5/24/77
RUN TIME: 6 Hours, 18 Minutes
TOTAL ENGINE RUN TIME: 44 Hours, 59 Minutes
ADH READINGS: No. 152 through 168

The purpose of this test was to evaluate the accelerating inlet acoustic panels. Prior to the test the core exhaust acoustic probe was repaired. The inlet Kevlar acoustic panels were removed and replaced with the original hard-wall panels. The lube system was serviced with 0.011 m³ (3 gal) of Royal 899 oil prior to the test; the oil level sensor indicating 0.078 m³ (20.5 gal). Also, one of the two oil deaerators in the oil tank was disconnected.

The test consisted of 40 sound and 17 ADH data points. Sound readings below 80% fan speed were taken with the undercowl cooling air off. The lube-supply temperature was held at approximately 333 K to 337 K (140° to 147° F) for the first portion of the test. However, while setting the 96% speed point (3680 fan rpm), the fault light on the digital control illuminated because of a high reduction gear bearing temperature, 402 K (265° F). After this, the lube-supply temperature was held between 322 K and 328 K (120° and 130° F), as in previous tests, with no further temperature problems encountered. Readings were taken at approach and takeoff conditions with nozzle flap angles of 11.5° and 25°. The first decline in oil level came after setting 96% fan speed for the first time. The oil-consumption rate then followed the same pattern as in previous tests. All of the planned testing (far field, near field, array, and probe data) was completed. The inlet throat, fan face, fan bypass duct, and core exhaust acoustic traverse probes were recorded at takeoff and approach power settings. The core exhaust probe was moved to four different locations in the exhaust stream during the test. Only one shutdown was required, this to move the core probe from the lower to the upper nozzle position.

The maximum fan speed tested was 96% (3680 rpm) with an indicated thrust of 84,067 N (18,900 lbf), as T41C again limited engine operation. The digital control and engine performed well as in previous tests; oil consumption was 0.042 m³ (11 gal). The undercowl temperatures remained well under limits for the entire test. The postshutdown inspection found no evidence of oil leakage or anything unusual.

RUN: No. 12 - Core/Acoustic Splitter Effect Acoustic Test
DATE: 5/25/77 and 5/26/77
RUN TIME: 5 Hours, 57 Minutes
TOTAL ENGINE RUN TIME: 50 Hours, 56 Minutes
ADH READINGS: No. 169 through 181

The purpose of this test was to evaluate the acoustic splitter and core nozzle acoustic treatment. Prior to this test, the following configuration changes were made:

- Removed hard-wall panels and installed Kevlar treated panels in the accelerating inlet.
- Removed acoustic splitter from fan duct.
- Removed treated core nozzle and centerbody. Installed hard-wall nozzle and centerbody.
- Replaced broken core cowl latch.
- The accessory gearbox overboard vent line, approximately 7.62 m (25 feet) in length, was replaced with a shorter line, approximately 1.52 m (5 feet) long. This shorter line was secured so that exhaust would run down the left side of the fan frame, leaving a visible

trace of any escaping oil residue. The purpose of the shorter line was to reduce the high oil tank pressure, noticed in the previous test, which may have been caused by back pressuring in the longer line.

- Removed fuel control metering valve, ΔP instrumentation, and re-installed engine piping.
- Serviced lube system with 0.042 m^3 (11 gal) of Royal 899 oil.
- Set fuel inlet pressure at 241 kN/m^2 (35 psig)
- Removed acoustic traverse probes from the fan face and inlet throat. Two acoustic probes remained, one each in the fan OGV duct and core exhaust.
- Adjusted nozzle side flaps to 11.5° .

The first attempted start was aborted due to a sudden drop in the facility air pressure which supplies the air starter. An additional facility air compressor was then hooked into the Site 4D system. The second attempted start was aborted due to a flameout at 8000 core rpm, at which time a sudden drop in fuel inlet pressure was noticed. The fuel inlet pressure was adjusted back to the original value of 517 kN/m^2 (75 psig), and a defective T5 signal was replaced on the panel digital display. The engine was then successfully fired-to-idle with engine start No. 38.

The test consisted of 13 ADH and 29 sound-reading data points, including data at approach and takeoff power settings with nozzle flap angles of 11.5° and 25° . Far-field, near-field, and dynamic pressure readings were recorded at all sound-data points, with array and probe data being taken at approach and takeoff power settings. The core probe was traversed at the two lower positions in the core exhaust. The engine was shut down to move the core probe to the upper position, but the probe was damaged during removal and further usage was eliminated.

Engine operation during the test was satisfactory. Lube level remained well behaved during the first 5 hours and 7 minutes of testing at speeds less than 94% (3620 fan rpm). A decline in lube level was first recorded while setting the max speed point allowed by the T41C limit, 95.7% (3627 fan rpm). Approximately 0.026 m^3 (7 gal) of oil was consumed during the 50 minutes it took to take array and probe data at this power setting. High aft undercowl temperatures forced the engine to be decelerated to 80% fan speed, for cooling, between the array and probe settings at this speed. Maximum indicated thrust was 82,550 N (18,560 lbf) at 95.7% fan speed and nozzle flap angle of 11.5° . This concluded the planned acoustic testing, and the engine was prepared for transient-response testing.

RUN: No. 13 - Transient-Response Test
DATE: 5/26/77
RUN TIME: 2 Hours, 12 Minutes
TOTAL ENGINE RUN TIME: 53 Hours, 8 Minutes
ADH READINGS: No. 182 through 190

The purpose of this run was to do transient-response testing using the digital control. Prior to the test, the core exhaust acoustic probe was removed and a Kiel probe installed in the lower center position of the core exhaust stream. Lube level sensor was indicating 0.051 m³ (13.5 gal) of oil. The Sanborn and tape recorders were set-up to record the transient test data. Nozzle side flaps were adjusted to 11.5°.

The engine was fired-to-idle without incident. A slow acceleration to the max allowable speed, limited by T41C, was performed with pauses at 1900, 2500, 3000, and 3500 fan rpm to record power-demand pot settings and calibrate the transient parameters on Sanborn. The Kiel probe was traversed while at 3500 rpm. Max speed obtained was 3622 rpm fan and 13,515 rpm core (95.5% fan speed) at a pot setting of 961. The engine was then returned to idle.

The procedure for running transients was to stabilize the engine using power-demand pot No. 1 (PD1), set power-demand pot No. 2 (PD2) at the desired transient speed point, set the Sandborn recorder speed at 0.05 m/sec, switch from PD1 to PD2, stabilize ten seconds, and switch back to PD1. In this manner, moderate transient accels were made from idle to 1900, 2532, and 3024 rpm fan speed and back again to idle without incident. The engine was then acceled to 2946 rpm fan and 12,555 rpm core to set approach thrust 53,820 N (12,100 lbf), using PD1. Transient accels were made from this speed to 3256, 3488, and 3672 fan rpm and back, again without incident.

While at approach power, the stators were reset 10° closed, with the engine speed stabilizing at 2943 fan and 13,344 core rpm, and ADH and panel readings were taken.

Two transient accels were made from approach power to 85% speed (3241 fan and 14,115 core rpm) and back. A transient accel to 92% speed was attempted, with the engine stabilizing at 3482 fan and 14,107 core rpm. A second transient accel to max speed was then attempted with the engine stabilizing at 3654 fan and 13,627 core rpm.

The stators were then reset 20° closed while at approach power and an ADH and panel reading taken. The engine was operating on the core speed limit (14,121 rpm) with a fan speed of 2853 rpm and indicated thrust of 49,900 N (11,220 lbf). The stators were reset to 15° closed to get off the core speed limit and reestablish approach thrust. The new approach power speeds were 2948 (77%) fan and 13,991 core rpm. Two transient accels to 85% fan speed were aborted as the core speed limit (approximately 14,100 rpm) was reached in both cases and only 80% (3030 rpm) fan speed was obtained. PD2 was adjusted for 92% fan speed and a transient accel to 3379 (88%) fan and 14,100 core rpm made; again, the core speed limit was reached during the accel.

The stators were reset to 12° closed, while at approach power, and PD2 set for max speed. A rapid-transient accel from approach to takeoff power and back was performed. Engine speeds stabilized at 3644 fan and 13,622 core rpm with an indicated thrust of 85,846 N (19,300 lbf). The stators were reset to nominal, and a normal shutdown was then performed to change the core exhaust Kiel probe to the upper/outer-most position.

The Kiel probe was moved and the engine fired-to-idle with Kiel probe data being taken at 3500 fan rpm. The engine was stabilized at approach power and the stators reset to 5° closed. ADH and panel readings were taken followed by an attempted transient accel to max speed. The engine speeds stabilized at 3595 fan and 13,610 core rpm during the transient before the decel back to approach. The stators were reset to nominal, and the normal shutdown was performed. This concluded planned transient-response testing.

Engine operation was excellent during the test; no vibration, blade stress, or lube system problems were encountered. Time was required to determine why the core speed limit was reached during transient accels from approach to takeoff power. Total oil consumption for the transient testing was approximately 0.004 m³ (1 gal). The postshutdown inspection showed nothing unusual.

RUN: No. 14 - Additional Test
DATE: 6/9/77
RUN TIME: 5 Hours, 11 Minutes
TOTAL ENGINE RUN TIME: 58 Hours, 19 Minutes
ADH READINGS: No 191 through 201

Prior to this test, the following configuration changes were made:

- Reconnected the second deaerator in the lube tank.
- Adjusted core speed limit upward 250 rpm to a new value of 14,500 rpm.
- Replaced two temporary load sensors (50-ohm resistors) with permanent load simulators on the A18 circuit of the digital control.
- Attached a static air/oil separator to the accessory gearbox overboard vent line. The oil drain line was routed to an accumulation receptacle on the ground. A flowmeter was installed in the vent line, before the separator.
- Installed a pressure tap to the accessory gearbox hydraulic pump pad cover, measuring gearbox pressure.
- Data recording equipment was set-up for acoustic and transient testing.
- Installed acoustic traverse probes at the fan OGV discharge and fan face.

- Set-up FICA test equipment and checked system.
- Secured a composite test specimen instrumented with one thermocouple in the aft undercowl core cavity directly behind the added cooling manifold and at 12 o'clock.
- Installed a grid of 16 tufts in four equally spaced rows and columns at the "D" nozzle exhaust to help identify exhaust flow direction.
- Serviced lube system with 0.038 m³ (10 gal) of Royal 899 oil.
- Adjusted T41C limit to 1733 K (2660° F).
- Adjusted nozzle side flaps to 25°.

The purpose of this test was to evaluate engine/control-system transients, lube system performance, acquire additional acoustic data, obtain additional exhaust flow directional information, and perform limited FICA tests. The engine was fired-to-idle without incident and stabilized at 3000 fan rpm where photographs of the nozzle exhaust tuft grid were taken. A problem was found in the T5 signal to the digital control, and the engine was shut-down to effect repair.

A different T5 signal was fed to the digital control, and the engine test was resumed with start No. 42. The engine was stabilized at 3000, 3200, 3400, and 3600 fan rpm, using PD2, for a period of 15 minutes at each point. This stabilization time was used to calibrate the Sanborn, record ADH and panel readings, check the oil-consumption rate, and record power-demand pot settings. An accel to the T41C limit of 1728 K (2650° F) was performed with the engine speeds stabilizing at 3627 (95.4%) fan and 13,540 core rpm. The two acoustic probes were traversed and acoustic measurements recorded as the above steps were repeated for this speed point.

The first decline in lube level was recorded while at 3600 rpm (94.4%) fan speed as the indicated level dropped from 0.055 m³ (14.5 gal) to 0.042 m³ (11.0 gal) in 20 minutes. Approximately 0.006 m³ (1.6 gal) of oil was consumed during the 15 minutes at max speed. This concluded the lube system and acoustic diagnostic portion of the test.

The procedure for running engine transients was the same as in the previous test. PD1 was set for 90% fan speed and transient decel from max (95.4%) fan speed was performed without incident. A slow decel to approach thrust, 53,820 N (12,100 lbf), was made using PD1 with the engine speeds stabilizing at 2891 (75.5%) fan and 12,575 core rpm. Several rapid-transient accels, followed by a 5-second stabilization and subsequent transient decel, were performed from approach power to maximum speed. The following adjustments were made on the engineering control panel prior to each of the listed transient runs.

<u>Transient No.</u>	<u>Adjustment To Engineering Control Panel</u>
1	No adjustment - all nominal pot settings
2	Adjusted core speed anticipation (Pot 4 to 1000), reducing N2 to minimum value.
3	Adjusted fan speed anticipation (Pot 13 to 420).
4	Further adjusted fan speed anticipation (Pot 13 to 220).
5	Adjusted T41C limit to 1733 K (2660° F) - Pot 16 to 840).
6	Further adjusted T41C limit to 1777 K (2740° F) - (Pot 16 to 900).
7	Adjusted accel schedule upward 4% - (Pot 7 to 550).
8	Adjusted accel schedule upward an additional 4%, 8% total of nominal (Pot 7 to 600).
9	Reset stators 25° closed (Pot 2 to 790).
10	Adjusted accel schedule an additional 2%, 10% total of nominal
11	No adjustments, repeat of transient No. 10.
12	Adjusted core speed anticipation back to nominal settings.
13	Adjusted fan speed anticipation back to nominal setting
14	Lowered fan speed anticipation to previous minimum value.
15	Reset stators to 15° closed position.
16	Reset stators to 5° closed position.

Transient runs No. 10 and 11 successfully demonstrated transient accels from approach thrust to 95% of takeoff thrust in 1 second. The stators and all engineering control panel potentiometers were returned to their nominal settings. This concluded the transient-response testing for this engine; the engine was slowed to idle for the start of the FICA test.

The FICA system was controlled from the engineering control panel by two switches. Switch No. 1 allowed the digital control to constantly monitor and update itself with the current engine operating parameters. Switch No. 2 activates the system whereby a failed sensor is replaced with a value of that parameter calculated by the digital control. A failed sensor would be indicated by a coded signal displayed in the "FICA Test" window of the operator panel, in which case both FICA switches would be turned off.

The PLA was advanced to 65° to provide a core-speed, override stop in case of a malfunction. Sanborn recorders were set at 0.025 m/sec.

FICA switch No. 1 was turned on and the engine acceded to, and stabilized at, 1900 and 2000 fan rpm. Switch No. 2 was activated for a period of three minutes at each speed without incident. After an accel to 2400 fan rpm, switch No. 2 was turned on; however, a fault in the "FICA Test" window was indicated and fan speed dropped to 1700 rpm. Both switches were turned off immediately, and fan speed recovered to 2400 rpm. A second attempt to activate both switches gave the same results. The PLA was advanced to 70° and both switches activated for three minutes. This time no fault was indicated.

A slow decel to 1900 rpm fan speed and subsequent slow accel back to 2400 rpm was performed with both FICA switches on. A fault was indicated when the engine speed reached 2400 rpm, and the FICA switches were deactivated. The switches were again turned on, with no fault indicated this time. A transient decel from 2400 to 1845 fan rpm was performed with both switches on, followed by a slow accel to 2400 rpm and decel to idle. No problems were encountered.

After advancing the PLA to 120°, a slow accel was made to 3587 rpm (94%) fan speed with switch No. 1 activated using PD1. PD2 was adjusted to this pot setting and the engine decelerated to approach power. A transient accel to 94% fan speed, followed by a normal decel to idle with switch No. 1 remaining activated, was performed. One final attempt was made for a transient accel from 1900 to 2400 fan rpm with both FICA switches turned on; however, a fault was indicated during the accel, and the FICA system was deactivated. This concluded the test, and a normal shutdown was performed.

The total amount of oil consumed during the test was 0.026 m³ (7 gal). No oil had accumulated from the static air/oil separator attached to the accessory gearbox vent. Other than for the FICA System test, the digital control performed satisfactorily. No problems were encountered with the engine operation. An extensive, postshutdown, engine inspection showed nothing other than normal engine wear. All oil-system filters and screens were removed and inspected with nothing unusual found. This concluded the testing for the QCSEE OTW engine.

7.0 TEST RESULTS

Major results of the OTW propulsion system testing are summarized as follows:

- Propulsion system performance in the forward-thrust regime, based on an equivalent conical exhaust nozzle, met the uninstalled thrust and sfc goals with a bellmouth inlet, and the installed thrust goal was met with an accelerating inlet. Turbine rotor inlet temperature exceeded the objective by 38 K (68° F) on a 305 K (90° F) day, which would limit the "flat rating" ambient temperature capability.
- Reverse thrust met the 35% goal at 81% corrected fan speed with a thrust-reverser blocker angle of 105° and 0.6 lip length ratio.
- Fan airflow exceeded the design intent by 2-3%, and fan efficiency exceeded the objective by 0.7 points. Fan hub supercharging exceeded design requirements by 3.4% pressure ratio. Fan stall limits were not investigated.
- The "D" shaped exhaust nozzle, operating in the forward-thrust mode, provided about 2° greater turndown of the exhaust stream than was predicted from scale-model testing. This reduced the axial thrust component but may be desirable from a powered-lift standpoint. Also, a slightly larger effective nozzle area might be desirable to allow the airflow to increase, providing greater inlet throat Mach number and improved acoustic suppression. The velocity coefficient was found to be about four points lower than predictions based on scale-model tests.

In the reverse-thrust configuration, pressure losses in the turn resulted in considerable back-pressuring of the fan, requiring a high fan speed to reach the 35% reverse-thrust goal. A larger nacelle cross section could alleviate this problem and improve the reverse-thrust noise level.

- The overall dynamic response of the engine was excellent. Rotor synchronous vibration was low throughout the operating range, and measured amplitudes were well within limits at all times.
- Fan blade dynamic response was entirely satisfactory. Vibratory response remained well within scope limits at all resonant speeds. The blades showed evidence of the onset of the stall/instability boundary while operating on an elevated operating line in the reverse-thrust mode at 115° blocker angle. Consequently, further reverse-thrust testing was done only with a 105° blocker angle to increase the effective exhaust area.

- The main reduction gear was not disassembled for inspection following the test, but data from bearing thermocouples, ring gear strain gages, and star gear proximity probes remained within limits at all times. Heat rejection data indicated slightly lower than predicted gear efficiencies.
- The accessory gearbox oil flooding problem encountered on the first OTW engine test was corrected by improved internal baffling and by elimination of the shop-air-powered eductor. Gearbox operation was entirely satisfactory during OTW testing.
- The composite fan frame indicated low stresses at all times and encountered no structural problems. Some oil leakage occurred from the accessory drive shaft midspan bearing region and from the accessory gearbox mount pad. These leaks were corrected by potting the areas with Furane 9210 adhesive. No further evidence of leakage was noted; however, some oil loss continued during high speed operation.
- The full authority digital control provided smooth starting without overtemperature, and stable, accurate, fan-speed control. T_{41} calculated by the control from sensed W_f , P_{S3} , and T_{T3} was fairly consistent with that calculated by the ADH system, showing this to be a promising on-line temperature indication. The engine met the required acceleration from 62 to 95% thrust in one second, using 25° core stator reset. The FICA system functioned in the tracking mode, indicating that the control was calculating parameters within the required range of accuracy. It failed to track properly when armed; however, analysis indicates that this may have been due to an error in control coding.

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